MOISTURE CONTROL & IAQ

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OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

UT-BATTELLE

Objectives

- **Moisture Effects & IAQ & Codes (Achilles)**
- **Introduce AEC/DOE Crawlspace Study (Bruce Davis)**
- **More Crawlspace Analysis (Achilles)**
- **Seattle Study (Achilles)**
- **Conclusions (Achilles + Bruce)**

Whats NEW in the NEWS ?

Sports

cbsnews.com
CBS NEWS

SEARCH
Go

NAVIGATE
- Home
- CBS News Broadcasts
  - The Early Show
  - CBS Evening News
  - 48 Hours
  - 60 Minutes
  - 60 Minutes II
  - The Saturday Early Show
  - CBS News Sunday Morning
  - Face the Nation
  - CBS Morning News
  - Up to the Minute
- National
- World
- WeatherWatch
- SciTech
- Eye on Politics
- Showbiz
- CBS News Polls
- Message Boards
- Career

CBS News | 48 Hours

An Insidious Mold

- *A Dream House Loses Charm*
- *Can Mold Cause Brain Damage?*

Sept. 28, 2000

CBS

Melinda Ballard says her dream house was invaded by a dangerous mold.

(CBS) Melinda Ballard and Ron Allison thought theirs was a dream house: a 22-room mansion on 72 acres outside of Austin, Texas.

Ballard, a former New York City public relations executive, thought it offered the perfect way to escape from the big city. **"It was my baby,"** she said. **"And it was truly a dream house for me."**

It's not a dream anymore. Ballard and Allison abandoned their home; they were forced to move out when their house was invaded by a mold that they say made everyone in their family sick. **Erin Moriarty** reports.

The couple's son Reese was the first to become ill at age 4. **"(He was) coughing up blood,"** Ballard said. **"His equilibrium was completely shot; very bad stomach problems; diarrhea; vomiting - it just spanned the whole globe in terms of symptoms."**

Soon Ballard became sick; she says she had trouble staying on her feet. Then Allison, an investment banker, began having trouble

Consumer advocate Kelly Hayes-Raitt of the HomeSafe

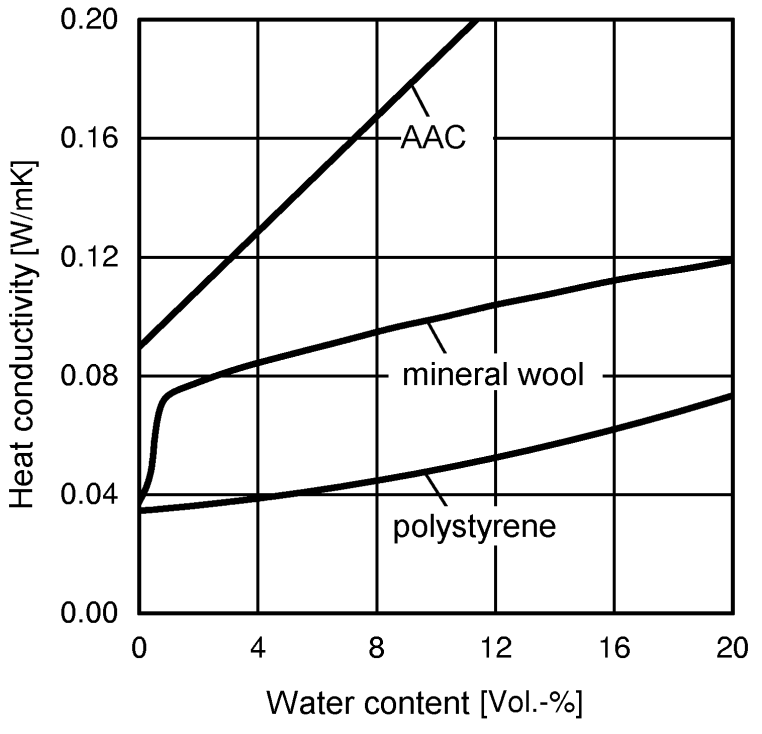
Some strains of Stachybotrys cause allergies, asthma and skin rashes. Others produce mycotoxins, released into the air. These toxins can seriously damage the lungs and central nervous system.

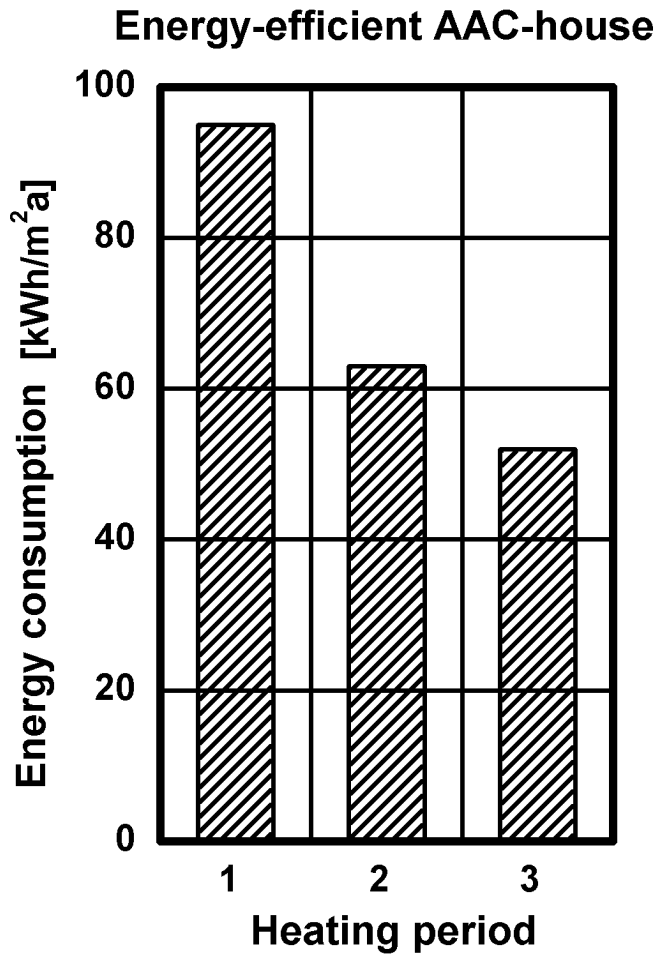
Internet

Moisture Effects

Increase of heat transmission

- Influence on the heat conductivity
- Latent heat effects





Ref.: Hartwig M. Künzel / Hans Erhorn

1. Moisture Effects

Optical degradation

- **Soiling, staining**

Outlining of the concrete structure beneath the plaster in a church due to differences in hygrothermal surface conditions (fogging)

Ref.: Helmut Künzel

1. Moisture Effects

Optical degradation

- Soiling, staining
- Microbial Growth
- Salt efflorescence

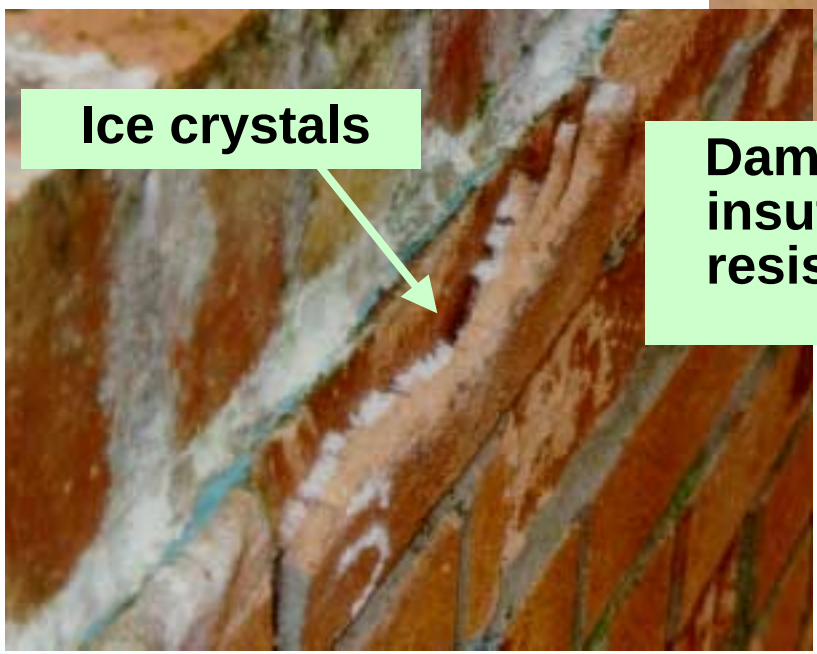
Lime efflorescence from mortar joints in brick veneer

Ref.: Jürgen Blaich

1. Moisture Effects

Damage caused by elevated water content

- **Freezing**



Damage due to insufficient frost resistance

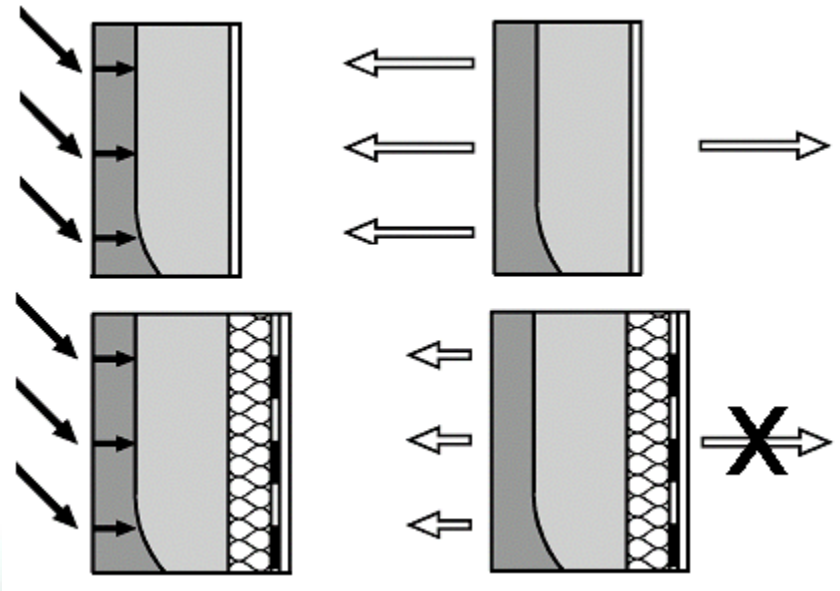
Ref.: Andreas Holm

1. Moisture Effects

Damage caused by elevated water content

- **Freezing**

Frost damage at stucco facade after applying interior insulation

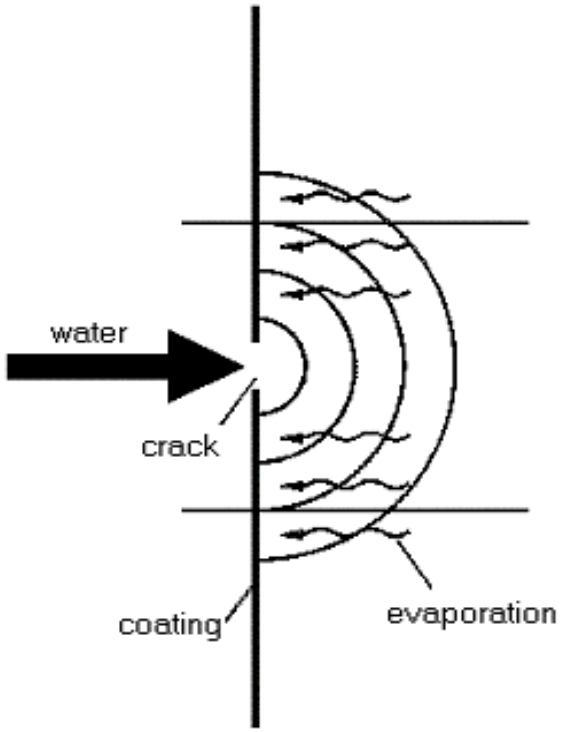


Ref.: Hartwig M. Künzel

1. Moisture Effects

Damage caused by elevated water content

- **Freezing**



AAC-wall with acrylic coating (gap bridging and vapor retarding)

Ref.: Hartwig M. Künzel

1. Moisture Effects

Damage caused by elevated water content

- **Freezing**
- **Rot**

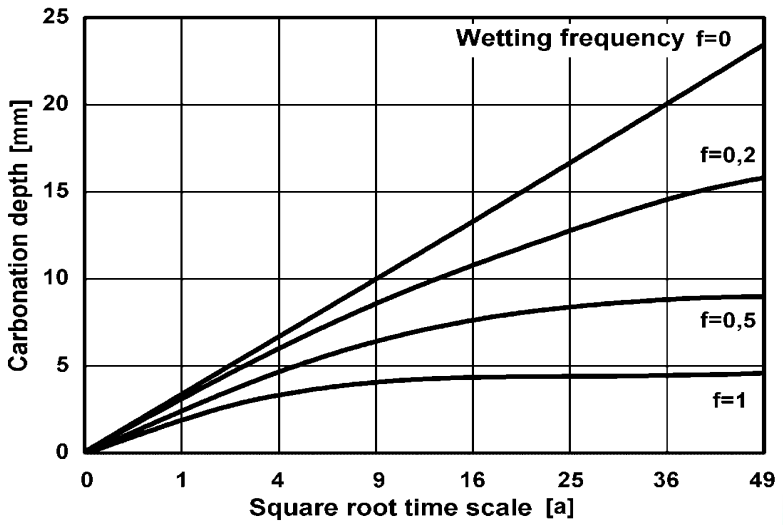
Rot caused by impermeable coating

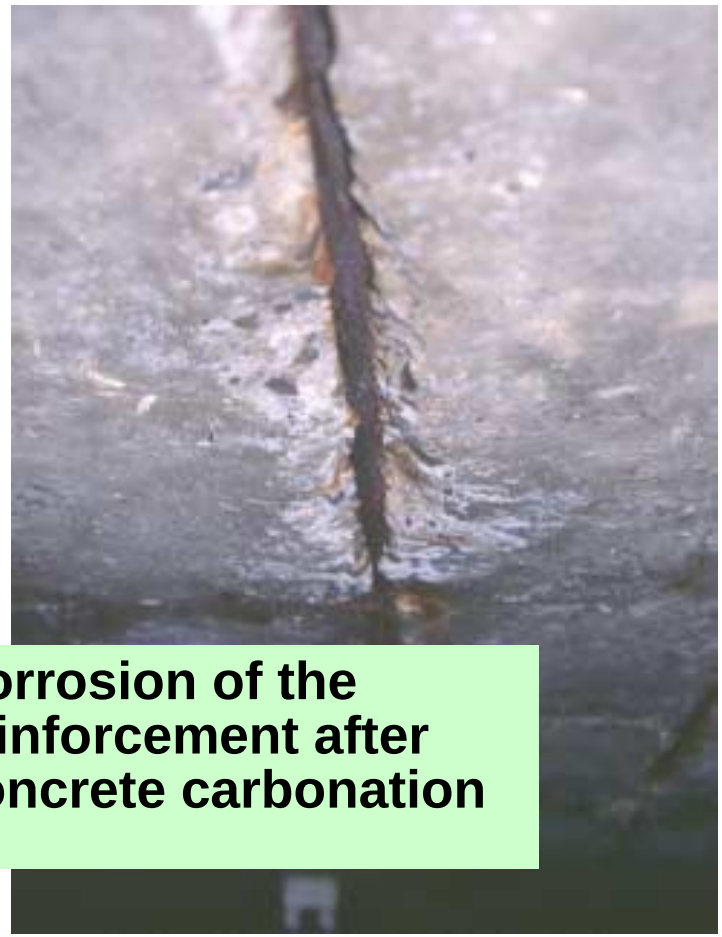
Ref.: Helmut Künzel

1. Moisture Effects

Damage caused by elevated water content

- Freezing
- Rot
- Corrosion





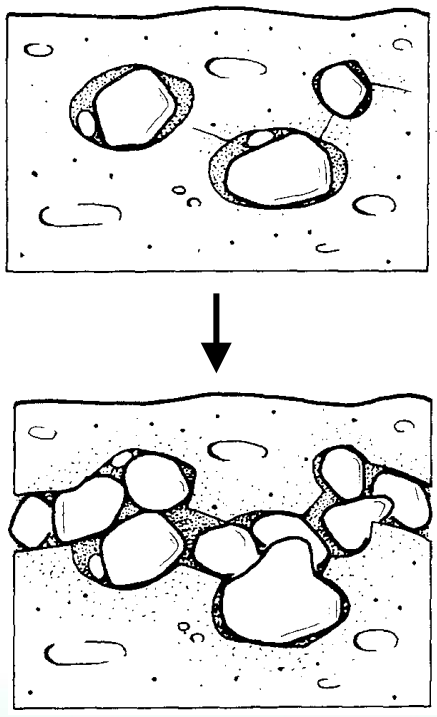
Corrosion of the reinforcement after concrete carbonation

Ref.: Michael Hergenröder / John Straube

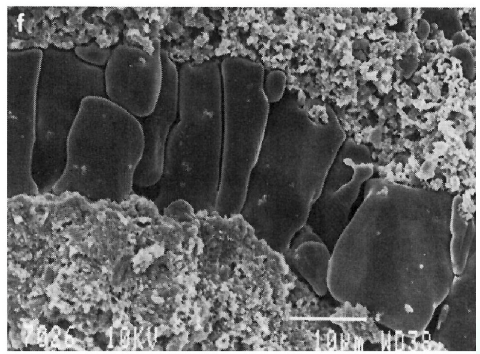
1. Moisture Effects

Damage by alternating stress

- Hygrothermal dilatation
- Salt crystallization



Degradation of sheltered zone through salt migration



Ref.: Zehnder & Arnold / Helmut Künzel

1. Indoor Air Quality

Health aspects

- **Hygrothermal comfort**

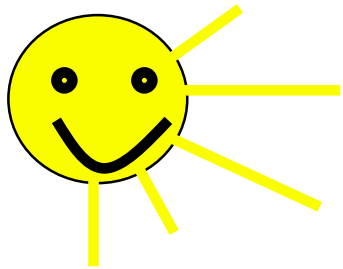
Relationship between
Exterior & Interior : Envelope

Ref.: Erhard Mayer / Brüel & Kjaer

Interior Loads

- Inhabitants
- Processes
- Plants/Animals
- Pool/Fountains/Humidifier/Dehumidifiers
- Other Sources

The Whole Building System



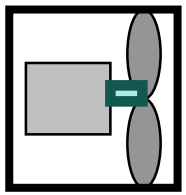
Moisture, Energy Production

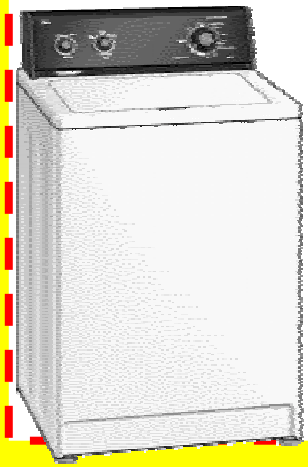
Energy +

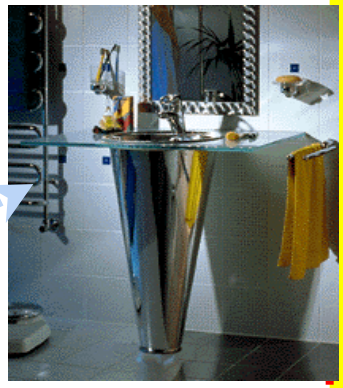
Air +

Moisture

HVAC





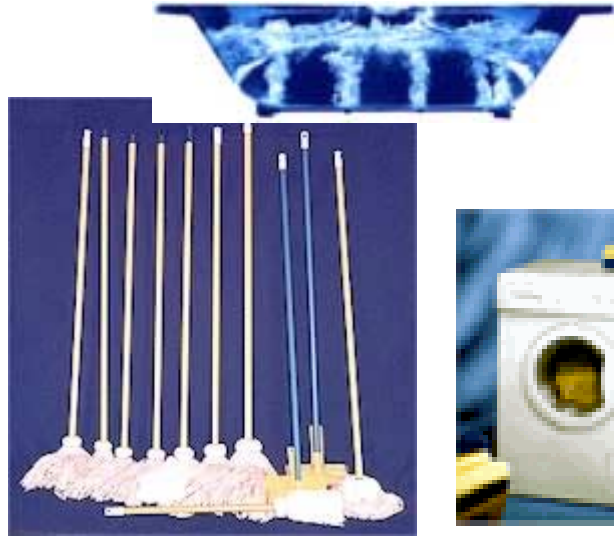


Out

House Loads

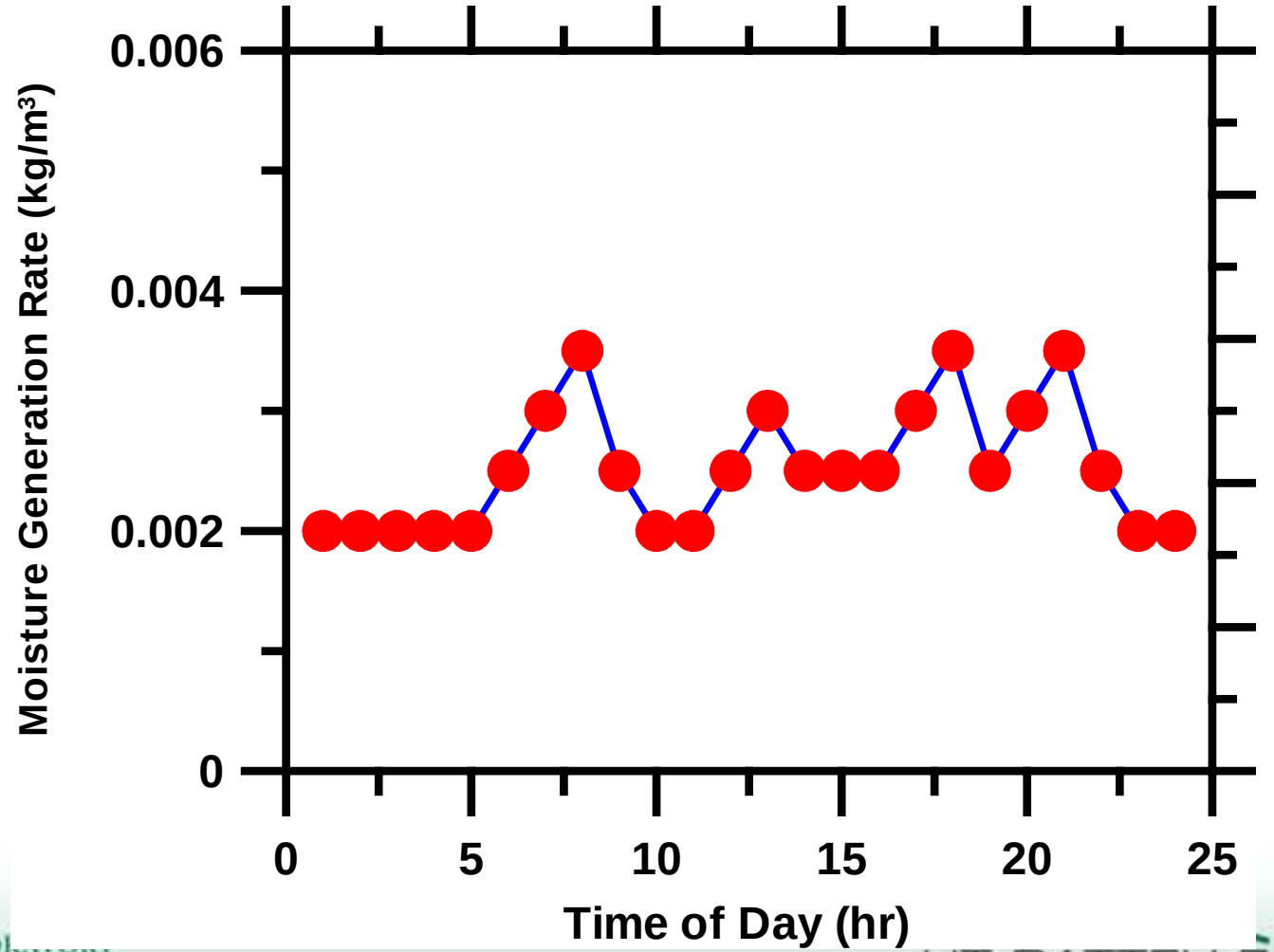
- **Define Interior Loads (IEA) (2 adults + 2 kids)**
  - **Human body (3.5 kg/day)**
  - **20 Plants (0.5 kg/day)**
  - **Personal Hygiene (1.3 kg/day)**
  - **House cleaning (0.2 kg/day)**
  - **Washing up (0.4 kg/day)**
  - **Laundry (1.8 kg/day)**
  - **Cooking (0.9 kg/day)**
  - **Miscellaneous (0.2 kg/day)**

TOTAL 8.5 kg/day (4 to 14 kg/day) (3.3 g/kg at 0.5ACH)



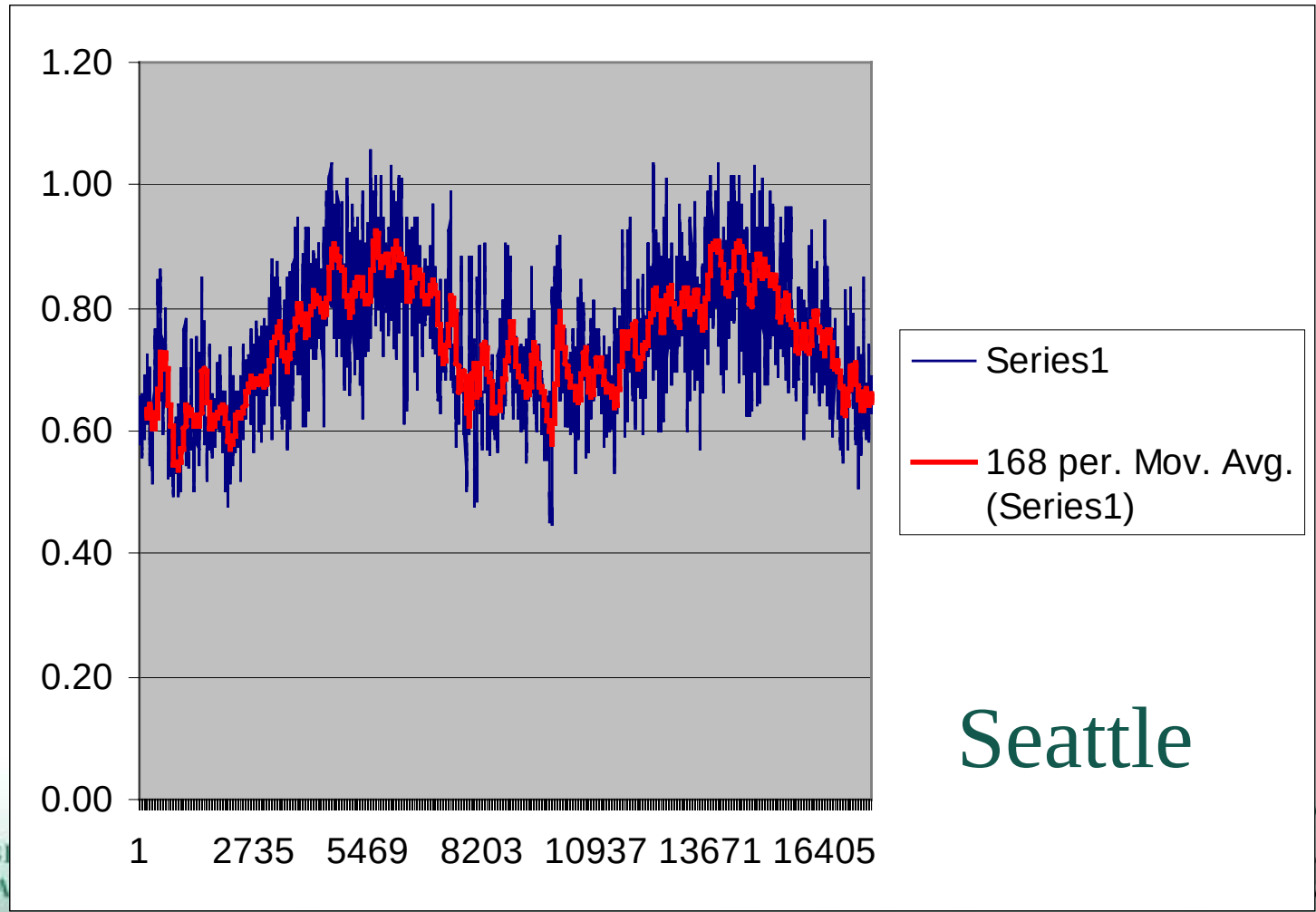
Interior Schedule

Hr	Moisture (g/m3)
1	0.00200
2	0.00200
3	0.00200
4	0.00200
5	0.00200
6	0.00250
7	0.00300
8	0.00350
9	0.00250
10	0.00200
11	0.00200
12	0.00250
13	0.00300
14	0.00250
15	0.00250
16	0.00250
17	0.00300
18	0.00350
19	0.00250
20	0.00300
21	0.00350
22	0.00250
23	0.00200
24	0.00200



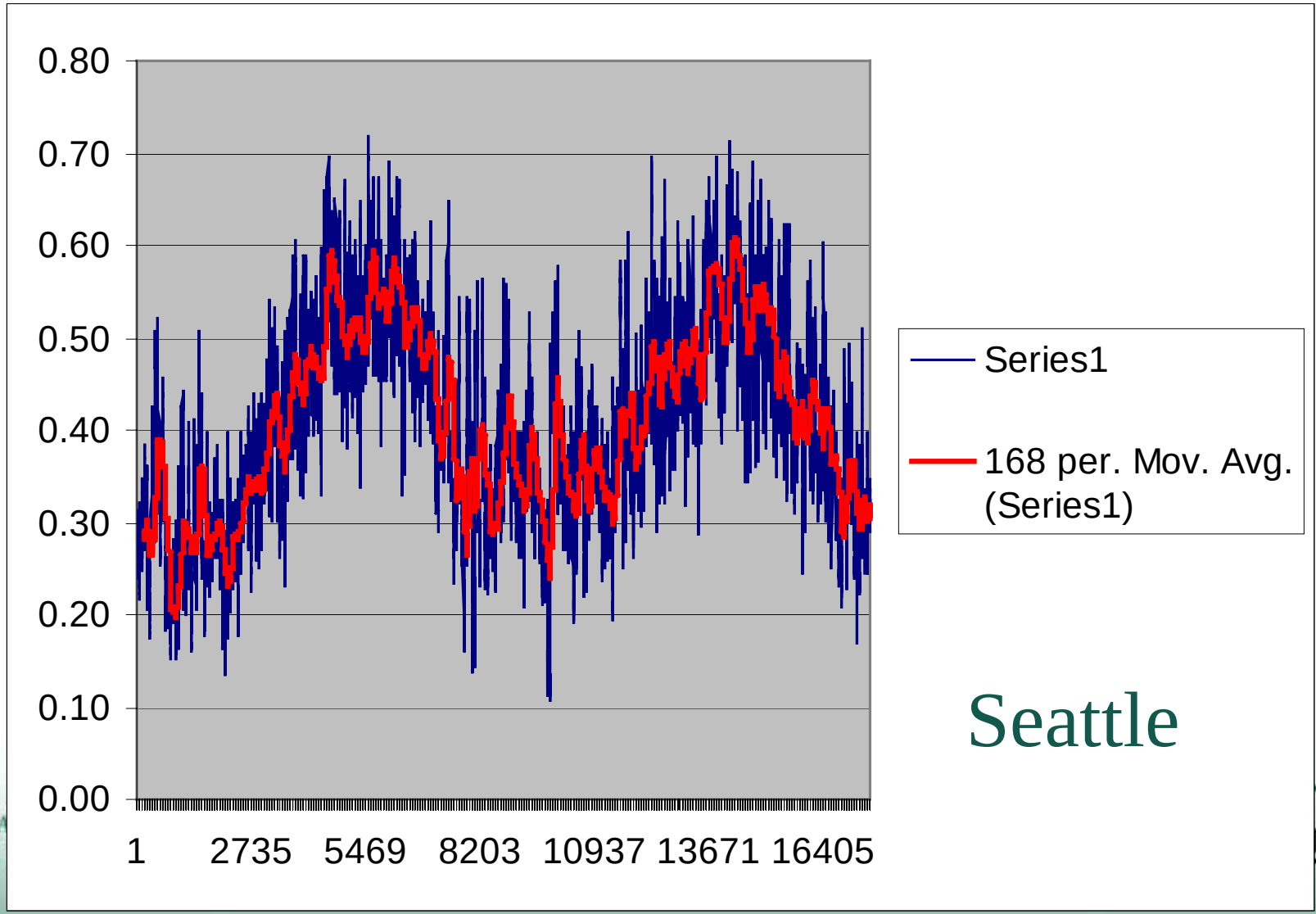
Effect of ACH + Moisture Production

T= 21 C, 10 kg/day, ACH=0.3, Area= 80 m^2



Effect of ACH + Moisture Production

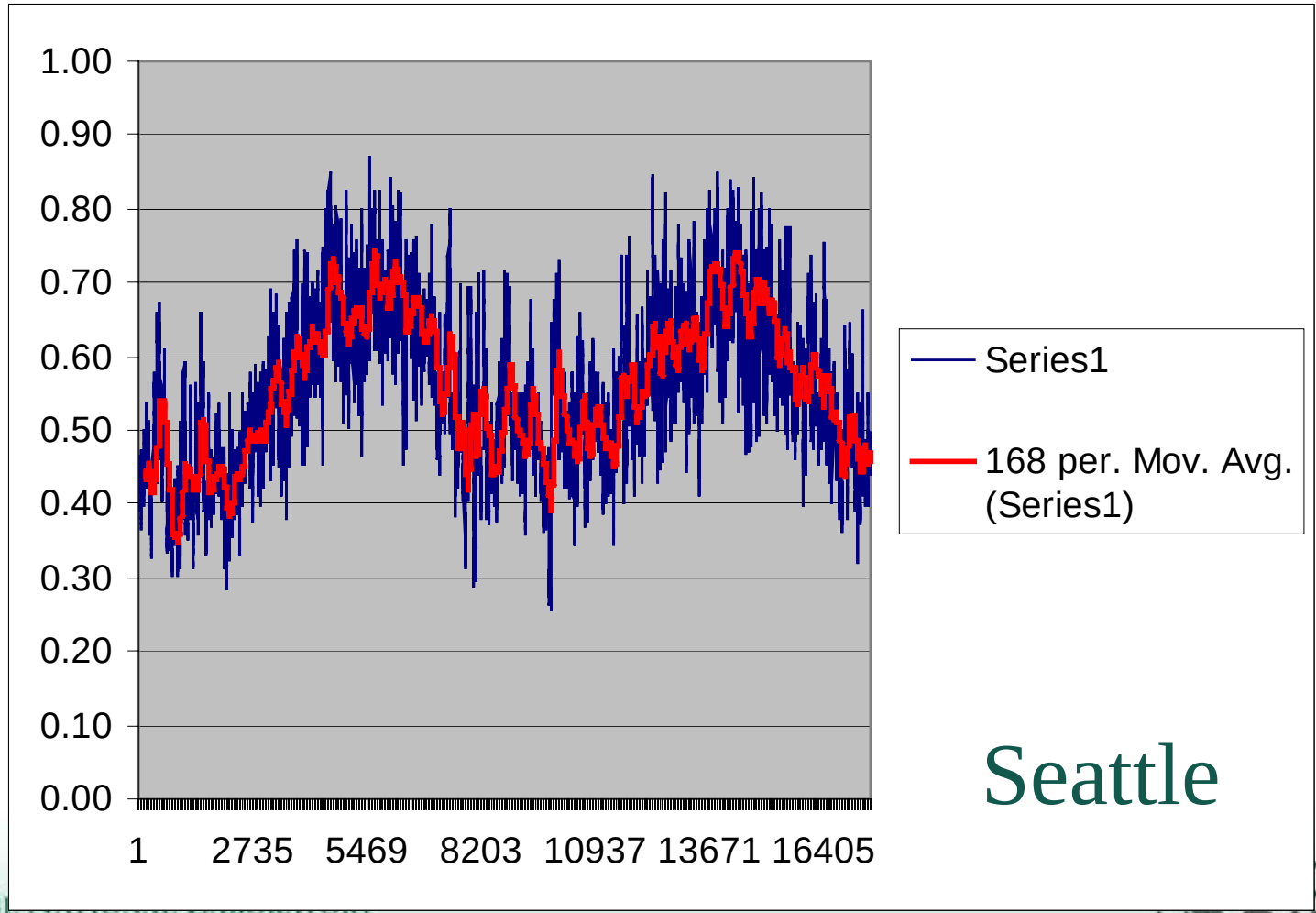
T= 21 C, 10 kg/day, ACH=3, Area= 80 m^2



Seattle

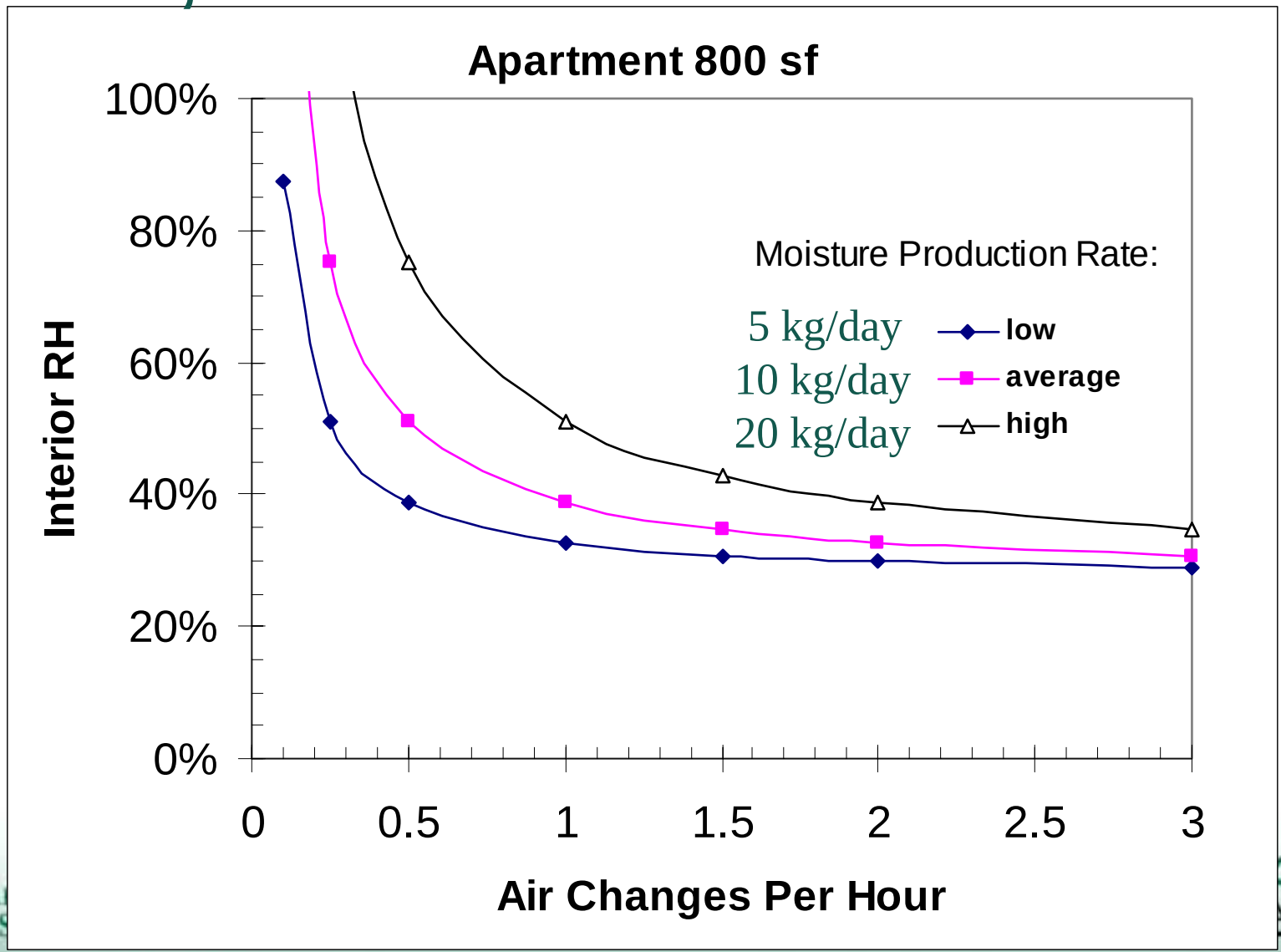
Effect of ACH + Moisture Production

T= 21 C, 5 kg/day, ACH=0.3, Area= 80 m^2



Seattle

Text= 5 C, RH = 80 %



Analysis of Apartment Buildings

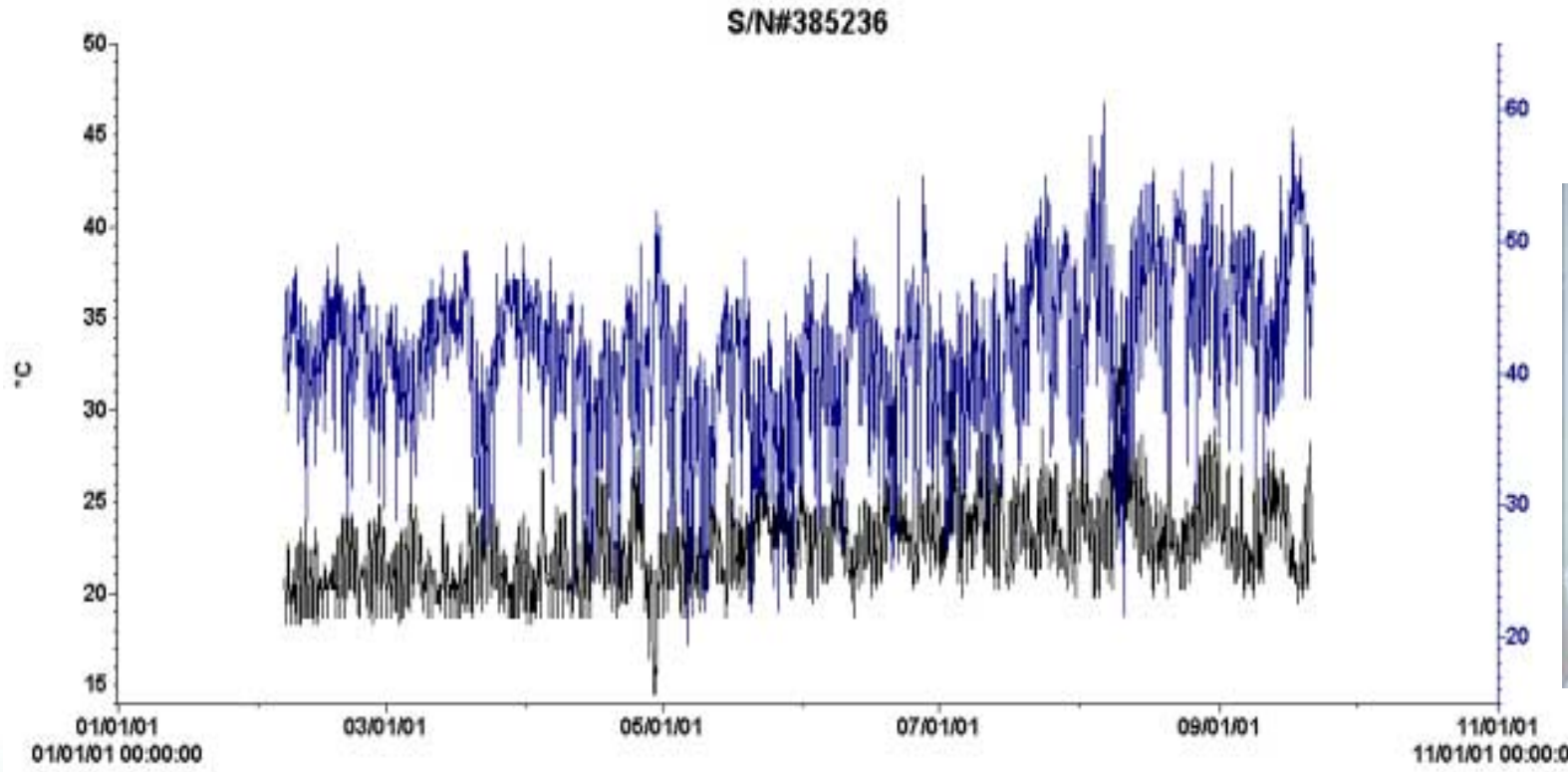
(g/m^3)
Measured Data
1.273294 0.55269
-0.39586 1.129046

Which **means** two things:

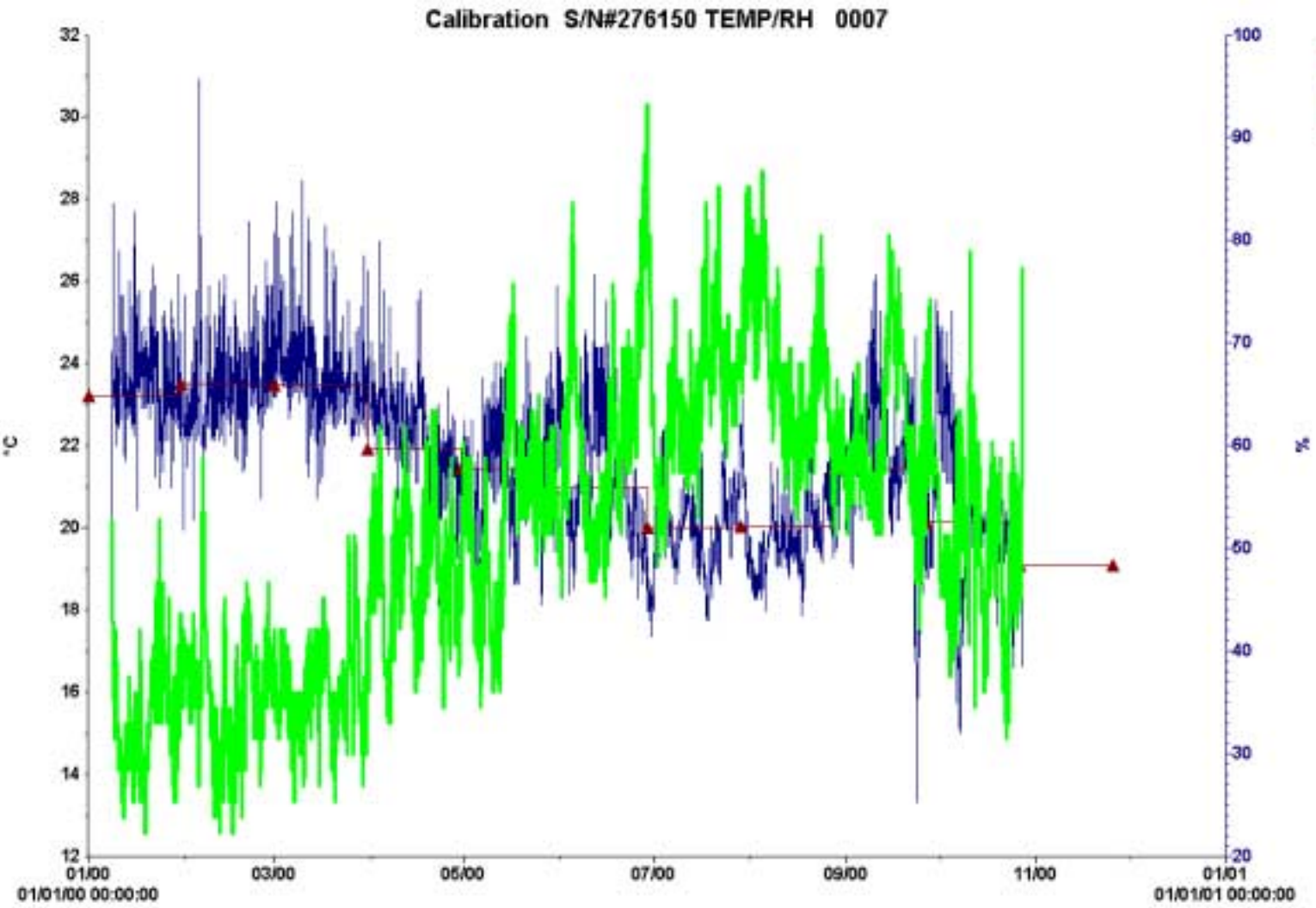
a) Unusual Dry Outside Conditions (Dry Year)

b) High Ventilation rates (0.8 ACH, at 5 kg/day)

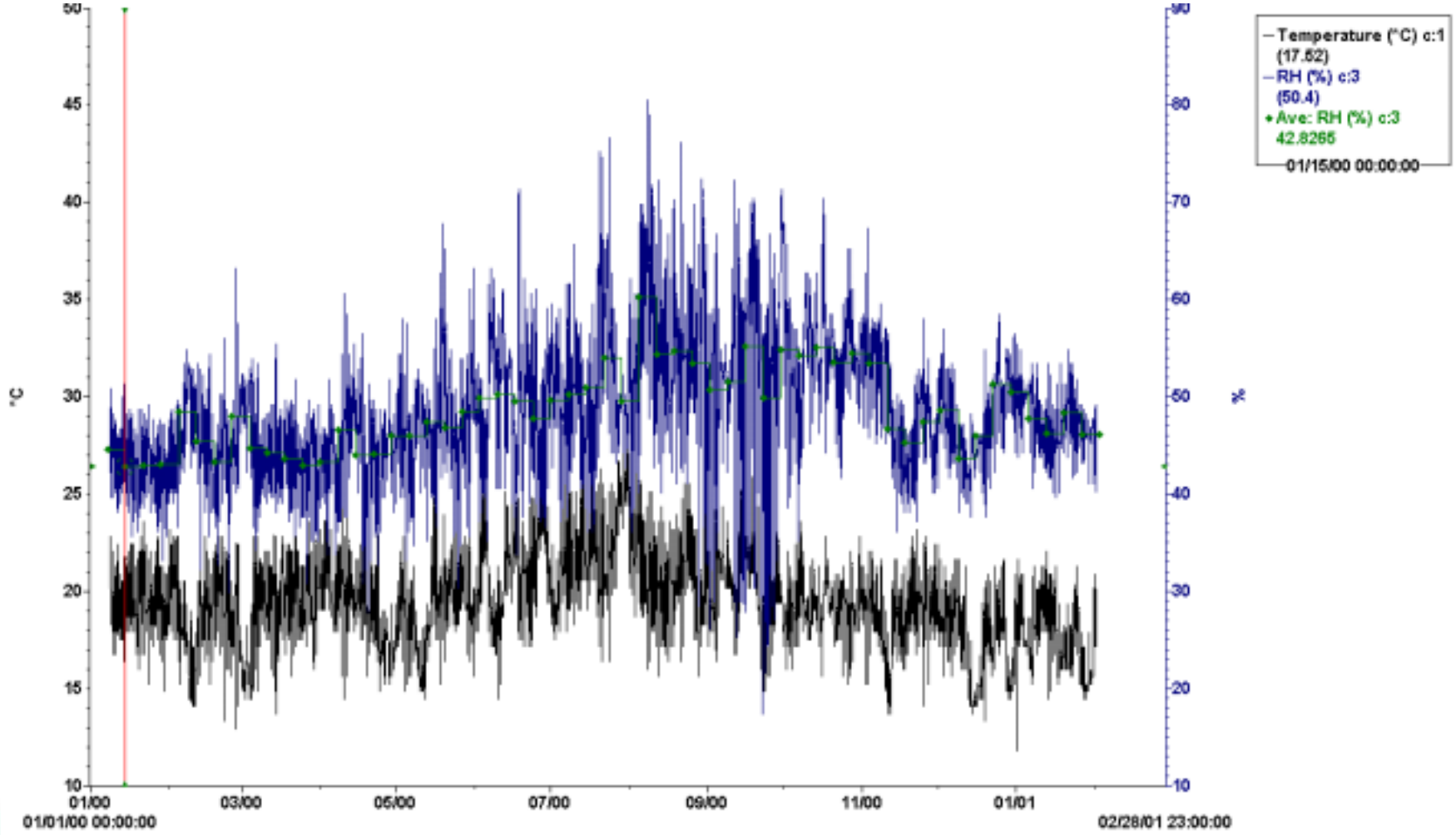
Seattle Measurements



Seattle Measurements



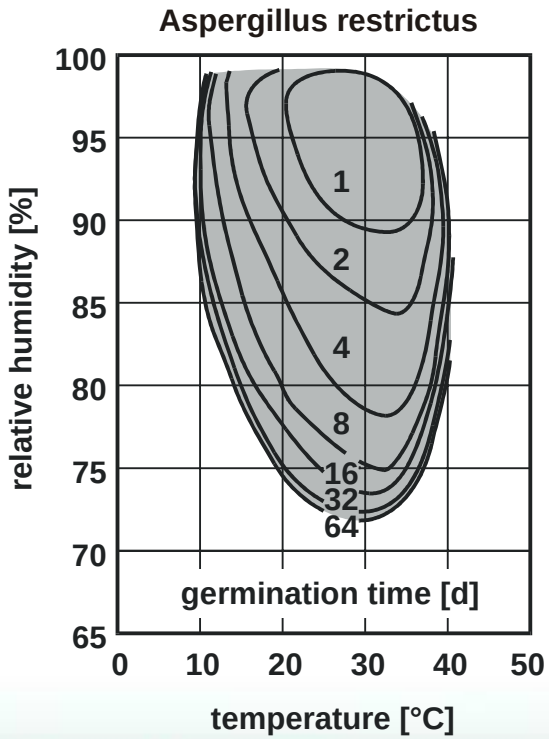
Seattle Measurements

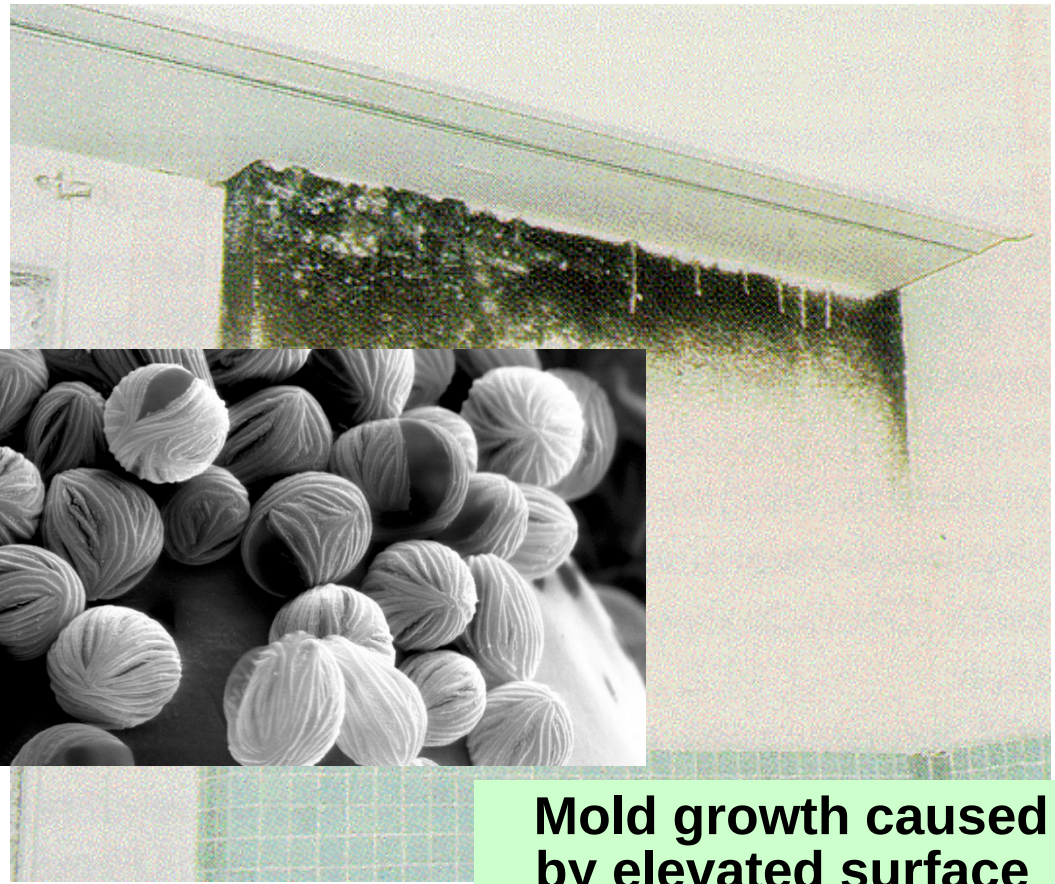


1. Moisture Effects

Health aspects

- Hygrothermal comfort
- Air quality





Mold growth caused by elevated surface humidity

Ref.: Klaus Sedlbauer

1. Moisture Effects

Health aspects

- Hygrothermal comfort
- Air quality

Microbial growth caused by summer condensation

Ref.: Helmut Künzel

1. Moisture Effects

Health aspects

- **Hygrothermal comfort**
- **Air quality**

Microbial growth behind vinyl wall paper (Florida climate)

Ref.: Joe Lstiburek

2. Modern Simulation Methods, Performance

Simulation of the real hygrothermal situation

- **Diurnal cycles (summer condensation, freeze-thaw)**
- **Seasonal cycles (interstitial condensation)**
- **Precipitation cycles (driving rain / solar radiation)**

Distinction of important influence factors (sensitivity analysis)

Extrapolation in time, transfer to different indoor / outdoor climate

Product optimization and development

Fast and cost effective

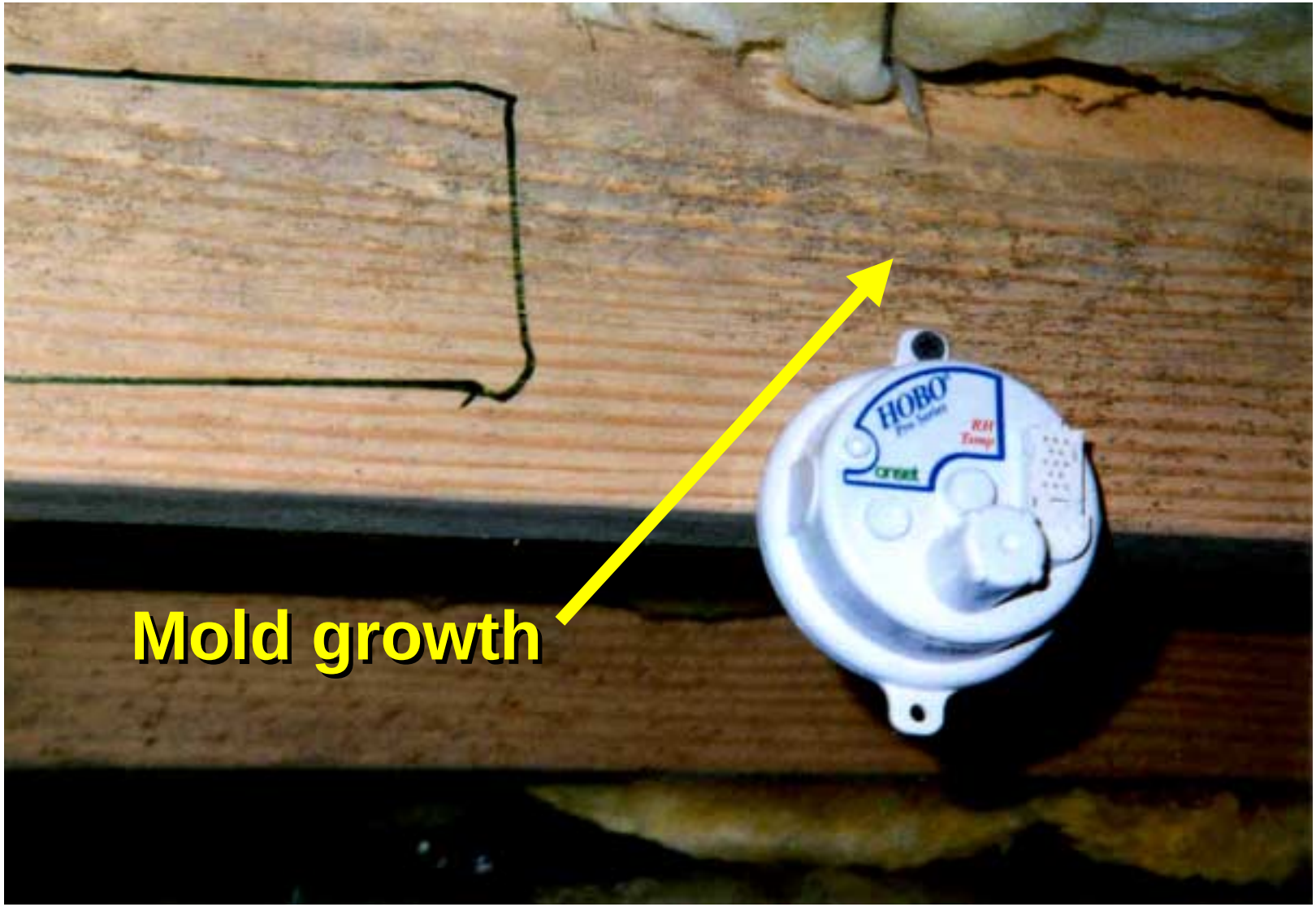
Expertise required

SystemVision™
by Advanced Energy

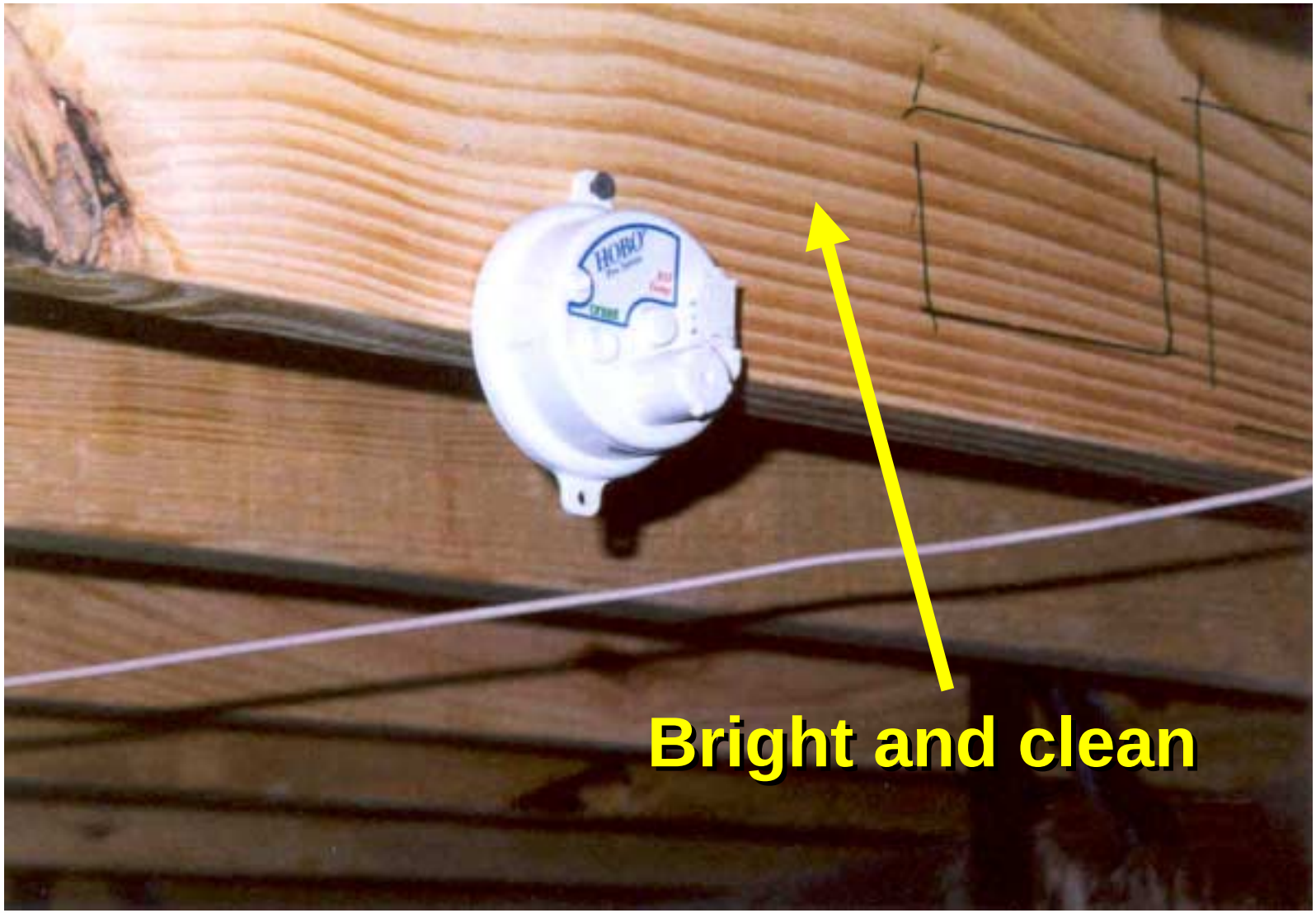
Bruce Davis

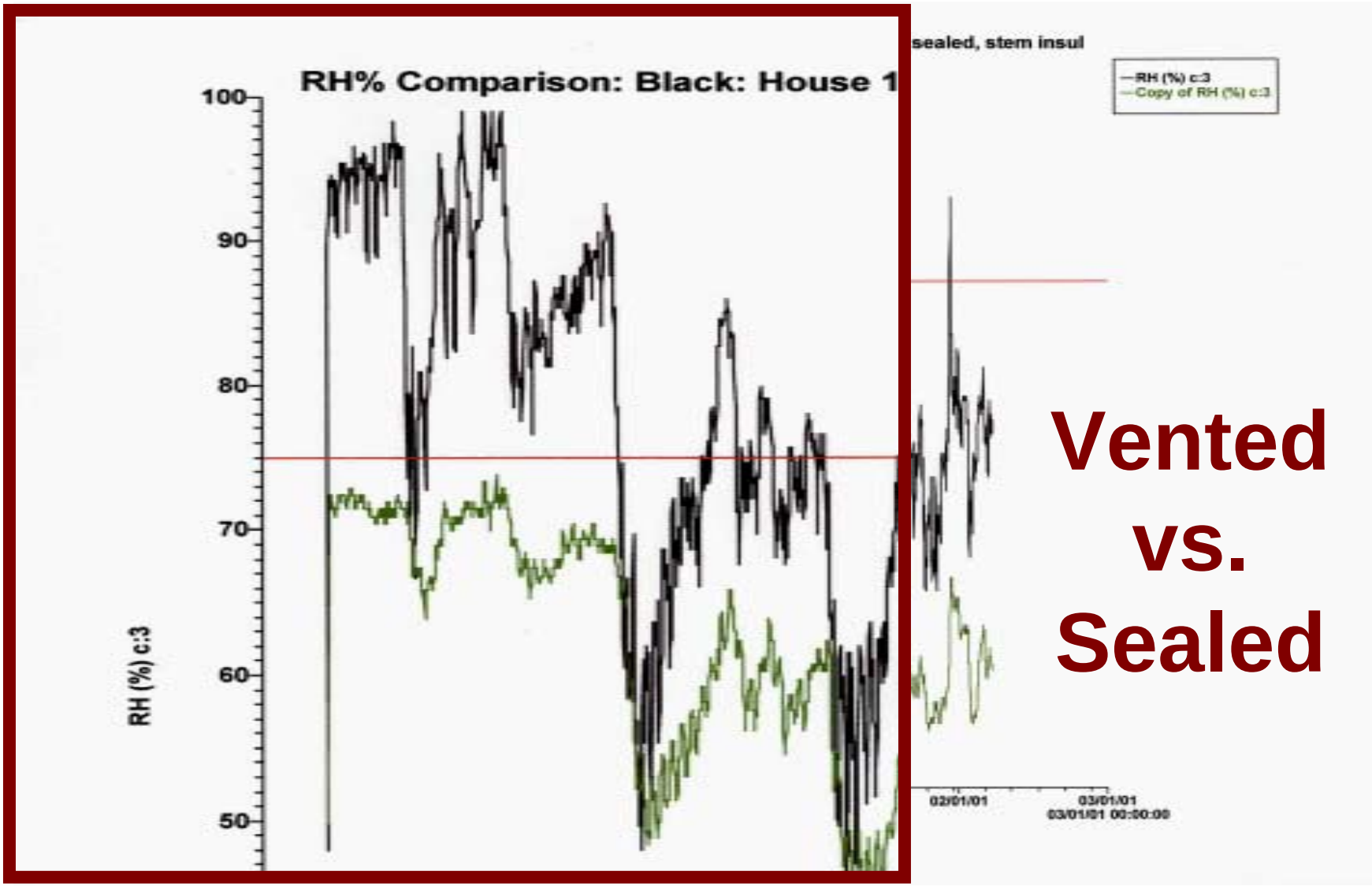
The Problem

Code vented, 2 years old



Sealed, 2 years old





Vented vs. Sealed

One style of sealed crawlspace

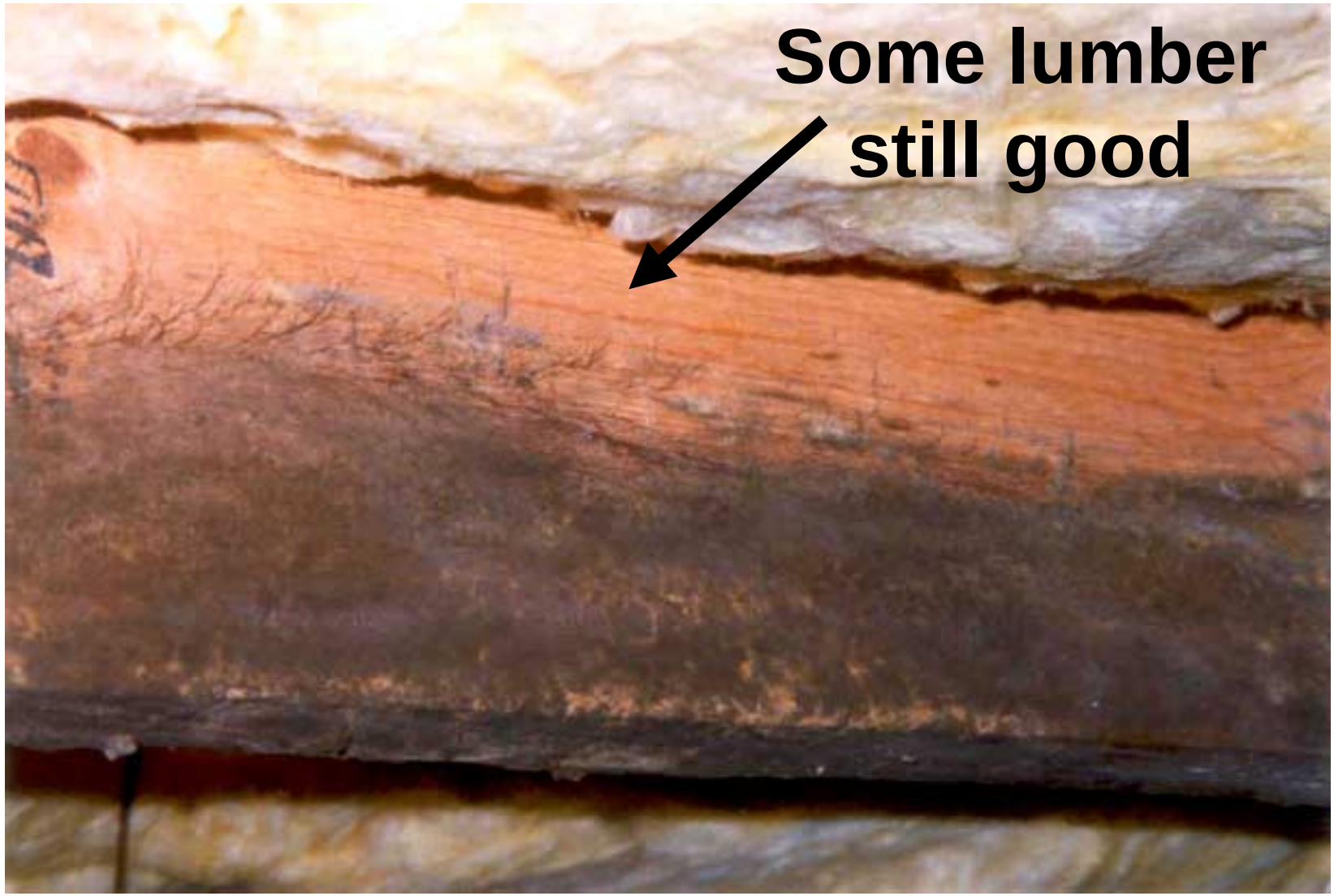
PCV* is not the answer!

***PCV = Power Crawlspace Ventilation**

Nice code house

What the pest control man saw

What the pest control man did



Some lumber rotten

So, do you want your floor saved this way?

Dry Crawl Space Construction

1. Characterization Study

2. Princeville Field Study

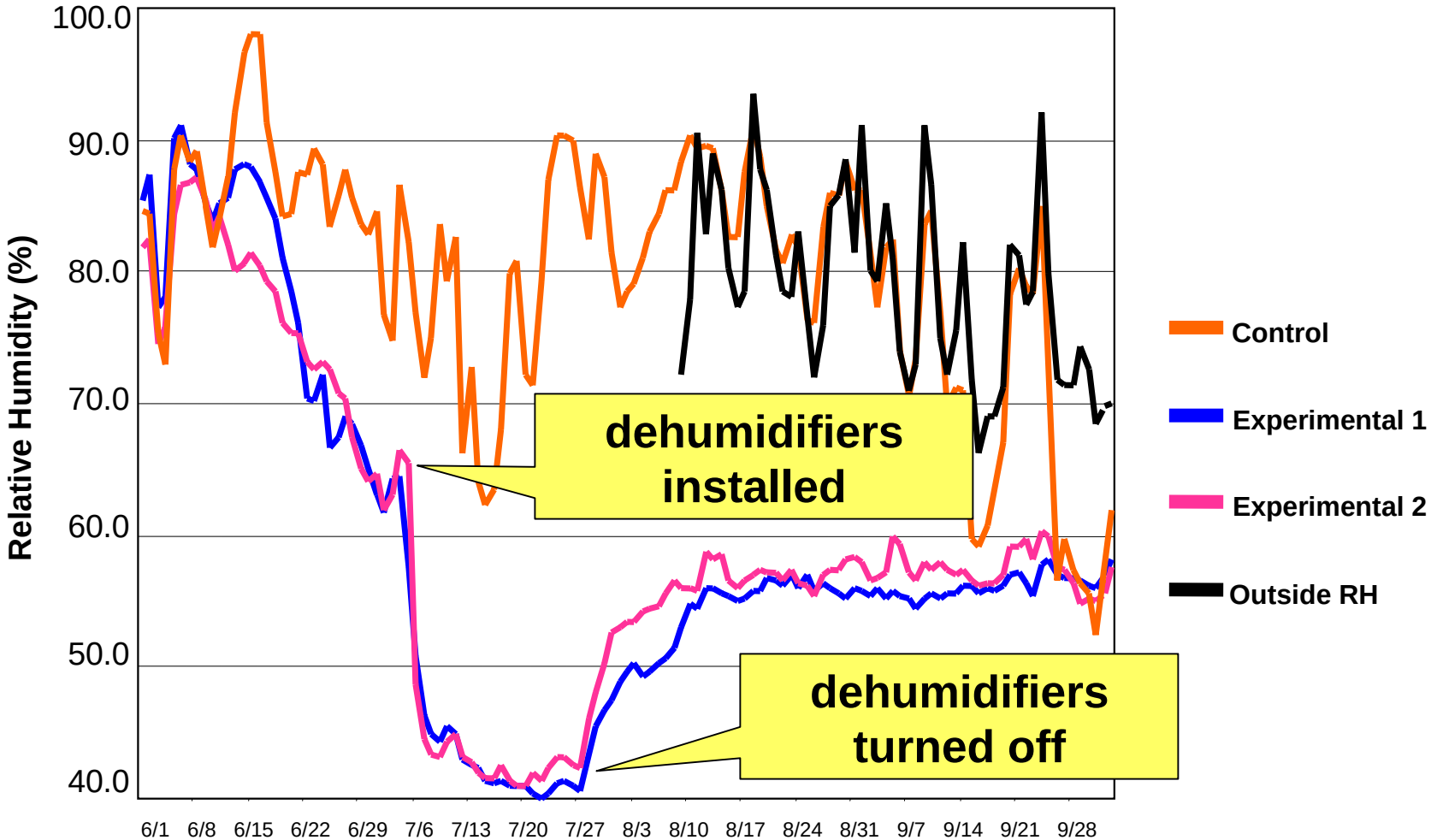
Temperature and species corrected wood moisture readings

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10
Sill Plate (Access)	15	14	18	12.8	15.8	14.8	14.2	14.9	17.1	16
Band Joist (Access)	14	14	16	13.7	15.6	15.2	15	13.5	16.4	11
Sill Plate (Worst)	19	17	20	13.8	17.1	21.9	15.6	17.9	14.5	17.2
Band Joist (Worst)	21	15	15	13.2	15.8	23.5	14.9	15.5	19.2	14.7
Center Beam	21	16	NA	14.7	20.3	17.9	19.2	14.2	18.8	16.2
Joist (Access Below Ins.)	16	15	18	14.7	16.5	16	15.3	14.2	20.5	15
Joist (Access Above Ins.)	14	13.5	14.5	12.5	11.3	13.6	10.8	12.1	16.2	11.6
Joist (Worst Below Ins.)	22	20	20	15.8	19.5	18.9	19.2	15.7	21	19
Joist (Worst Above Ins.)	17	15	12	12	12.8	14.3	17.2	12.3	18.4	15.2
Sub flooring	12	18	NA	10.5	16.6	14.1	16.7	16.6	15.6	15.8
Average 1-9, 11	17.7	15.5	16.7	13.7	16.1	17.3	15.7	14.5	18	15.1
Maximum	22	20	20	15.8	20.3	23.5	19.2	17.9	21	19
Minimum	14	13.5	12	12	11.3	13.6	10.8	12.1	14.5	11

Wood Moisture Content

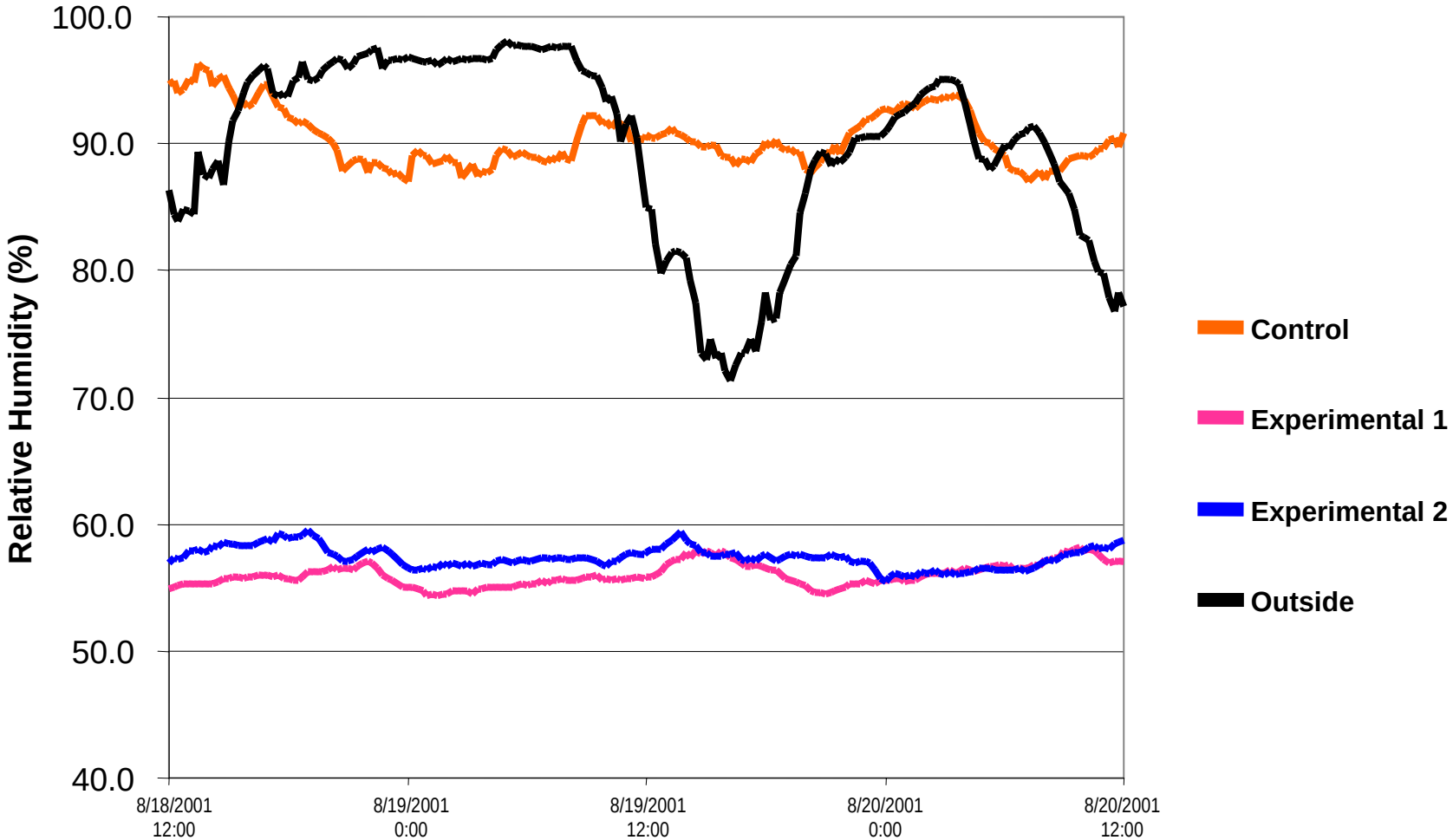
- Control 14.0
- Experiment 1 9.5
- Experiment 2 9.4

August 31, 2001



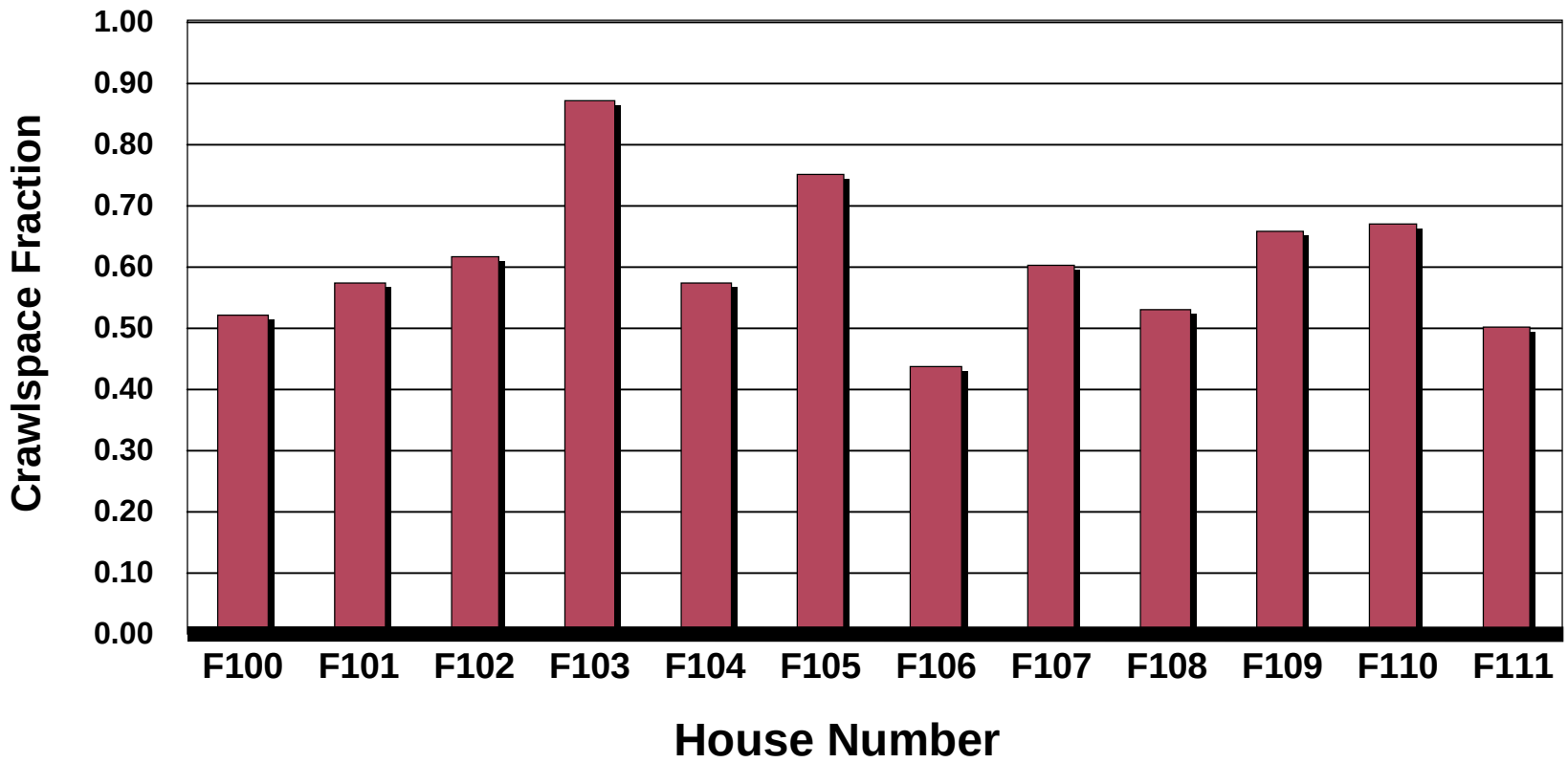
Percentage of time that field study crawl spaces were above certain relative humidity levels

	Control	Expmt. 1	Expmt. 2
Above 90% Relative Humidity	16%	0%	0%
Above 80% Relative Humidity	60%	0%	0%
Above 70% Relative Humidity	79%	0%	0%
Above 60% Relative Humidity	100%	3%	16%
Above 50% Relative Humidity	100%	100%	100%



Fraction of Ventilating Air Passing Through Crawlspace

NOTE: Assuming OA Radon Levels are 0.2 pCi/L



So, what have we learned?

What is this?

Dry Crawl Space Construction Must Address

- Pest control
- Moisture control
- Fire standards
- Thermal standards
- Radon control
- Gas warning and shutoff when gas is used

Most Codes Now Allow Dry Crawl Spaces

If you read in detail all the crawl space related provisions in most codes, and you address each of those issues, and you present your code based multiple solution plan to a code official at the design stage, chances are good that you will be allowed to build a dry crawl space.

SystemVision™
by Advanced Energy

Pilot Study: Hygrothermal Analysis

A. Scope of Work:

The overall research goal is to investigate the thermal, moisture and indoor air quality performance characteristics of sealed versus ventilated crawlspaces for residential buildings in the South.

ORNL's research activities concentrate on the development of scientific hygrothermal performance data of crawlspaces by means of experimental field monitoring, and advanced hygrothermal modeling of a defined set of crawlspace designs.

Crawlspaces

- Major source of moisture is soil & surface
  - So, use good ground cover, drain spaces
- Crawlspaces are often cooler than exterior
  - no sun to provide heating
  - huge thermal mass of earth/soil is usually cooler than air temp
- Therefore venting will often bring moisture in
- Venting in hot-humid climates is lunacy
- No good reason to vent

The Issues

Failure of some systems during the last years !!

Northern Climates

- Work well documented for Northern Climates
- Optimal Selection of ground covers/ventilation

Mixed Climates

- Better Understanding needed ! (Think we know one solution)

The Issues

Northern Climates (cold.... Jarek):

1) Ventilation and air change rate not key issues for moisture balance

a) Ventilation can not compensate ground moisture evaporation (uncovered crawlspace), crawlspace RH can not be significantly reduced.

b) Unventilated can work only when all evaporation and other possible moisture sources are entirely prevented/controlled.

The Issues

....Northern Climates:

2) Effective insulation of cold ground is needed to:

a) Increase crawlspace Temperature

b) Reduce RH during critical summer time

3) Ground cover needs high thermal insulation and low thermal capacity (decrease thermal lag)

The Issues

....Northern Climates (cold):

4) 150-300 mm (6 to 12 in) lightweight aggregate and 50-100 mm (2 to 4 in) EPS (cover)

5) Never use Plastic for cold crawlspaces

6) Never have an uncovered crawlspace for any climate

7) Two step air change 0.5-1 ACH heating season and 2-3 ACH for warm season (May to Oct)

The Issues

Northern Climates (warmeeeer crawlspaces):

1) Use Ground covers (60 to 70 % RH)

   a) Moisture Resistance of ground cover

Moisture Problems

Crawlspaces

1) Rainwater, Sewage, water spring, drainage

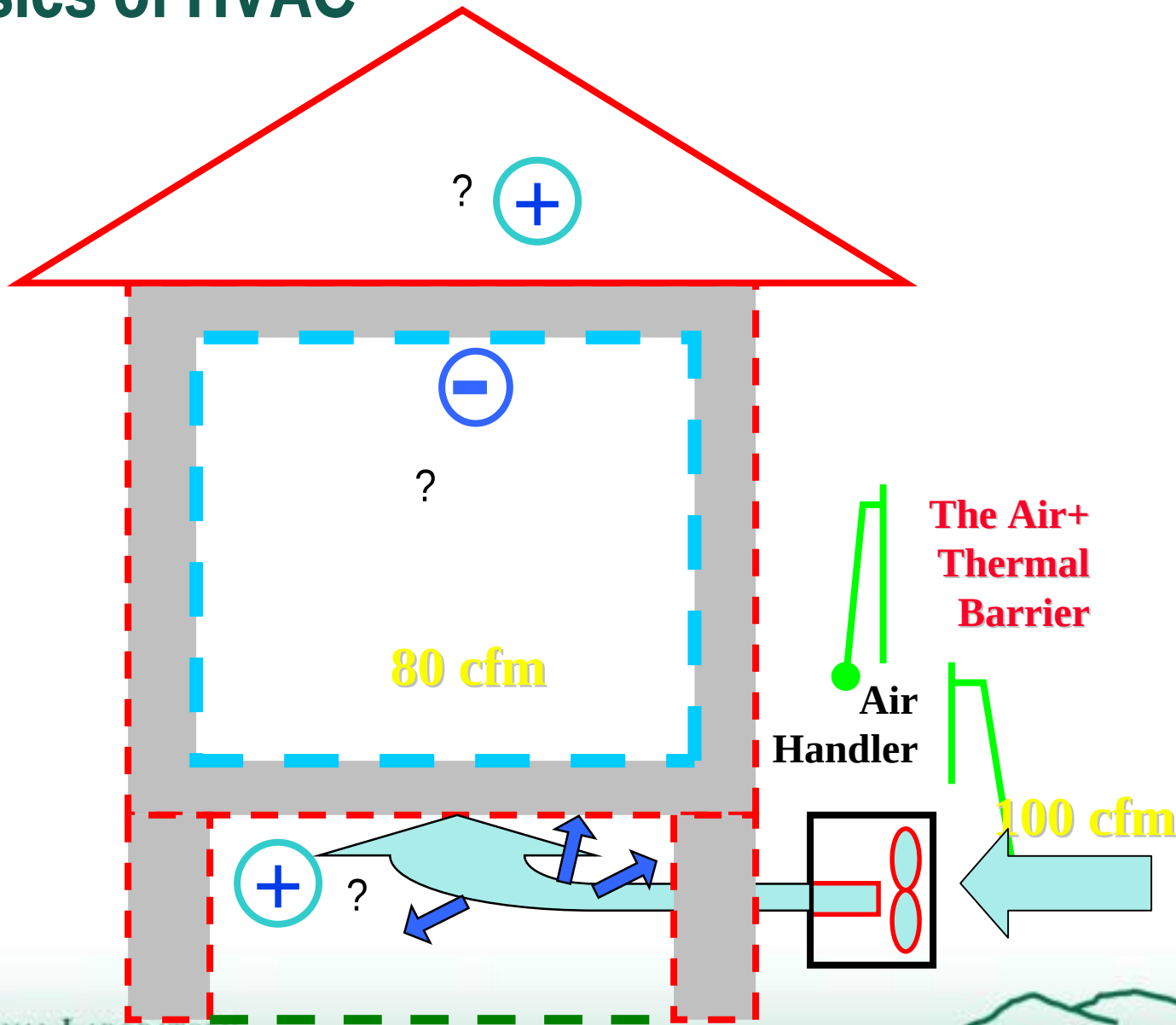
2) Thermal Lag

3) Low Temperature (Highly insulated base floors + high heat capacity of floors)

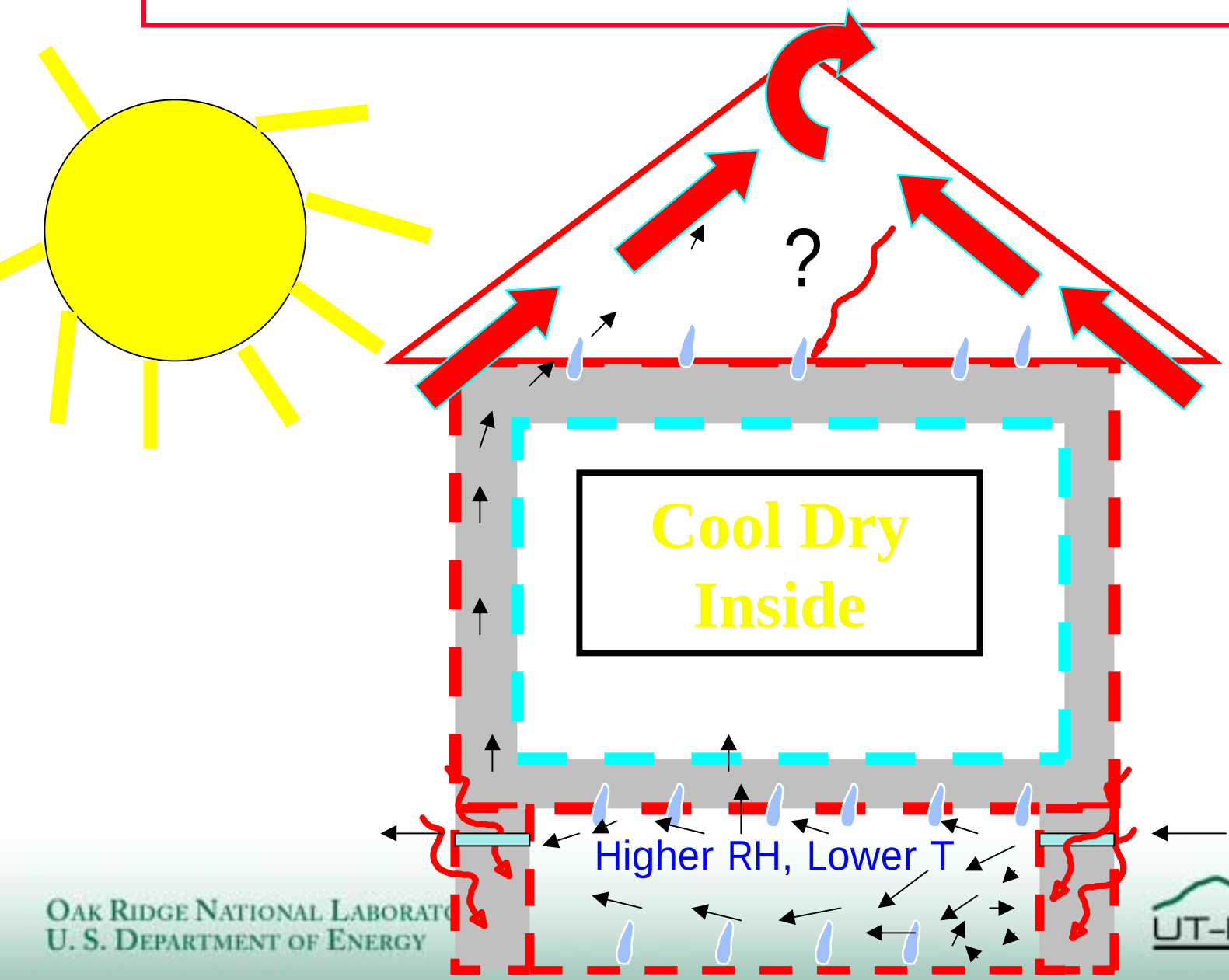
4) Soil hygro material properties

4) No heaters + Dehumidifiers

The Physics of HVAC



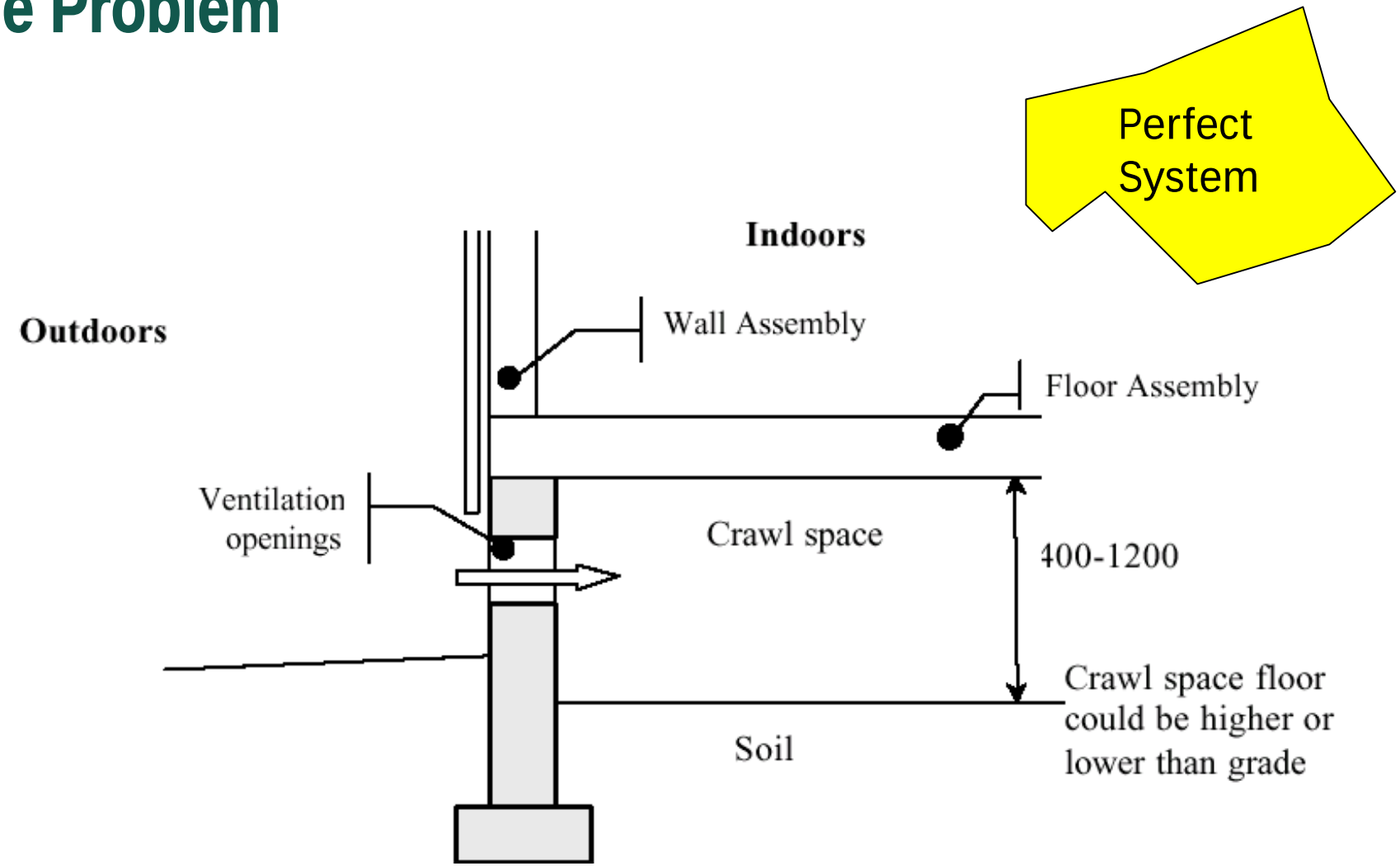
Problem: Hot and Humid Condition



The Moisture Physics

Next Time

The Problem



Previous Works

Crawlspaces Publications

1) Rose & TenWolde (ASHRAE Publication) Historical Review

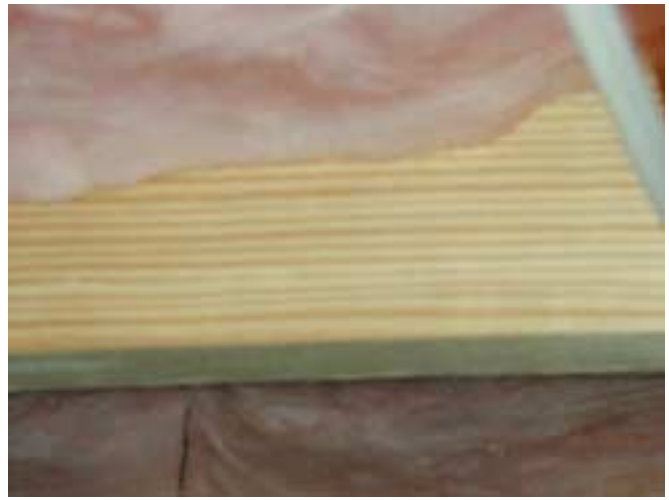
2) Britton (1940) Ventilation helps (ground cover more important)

3) Jones (1956) (close ventilation, but ground cover)

4) Samuelson, Jarek, Hagentoft, Lars-Erik Harderup (Well Ventilation even today)

5) Lstiburek, IEA Annex 24

The Crawlspace Perfection (1 year old)



S O M E T H I N G S

Right !

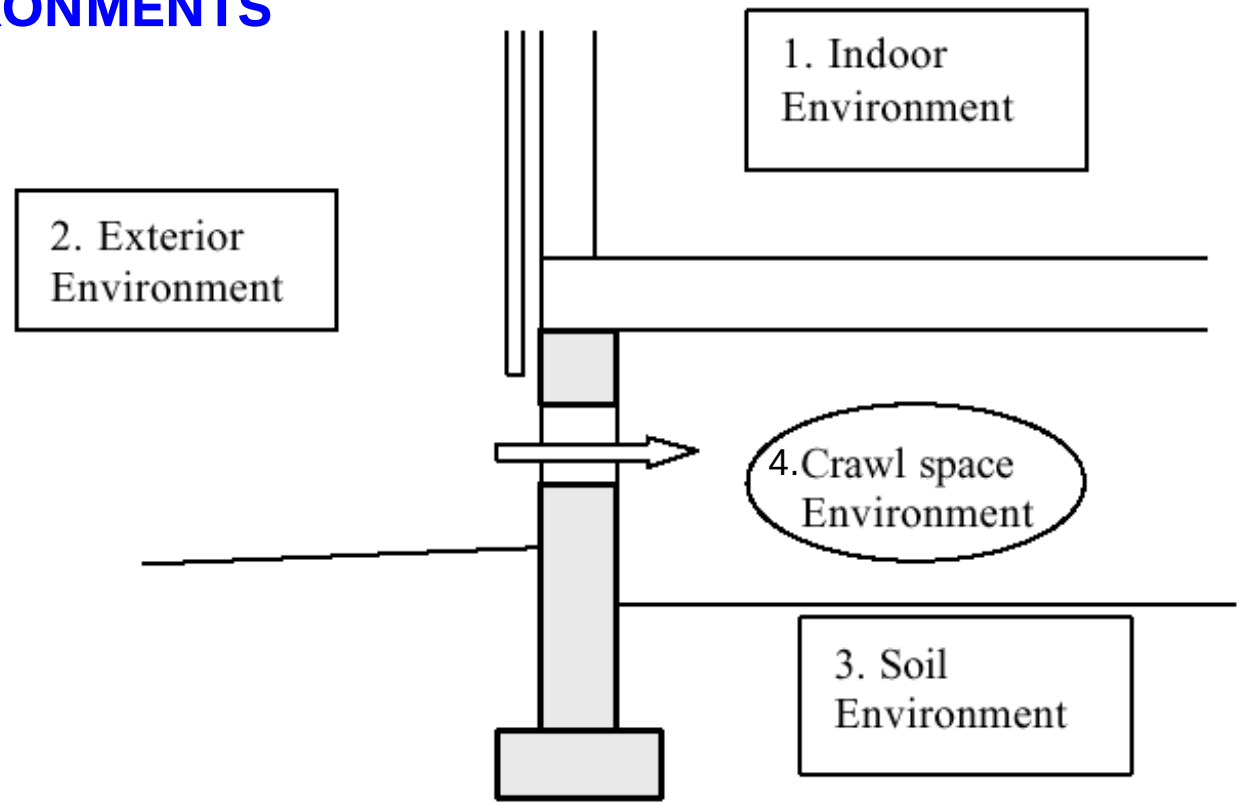
The Crawlspace Problem (1 year old)

SOMETHINGS

Wrong !

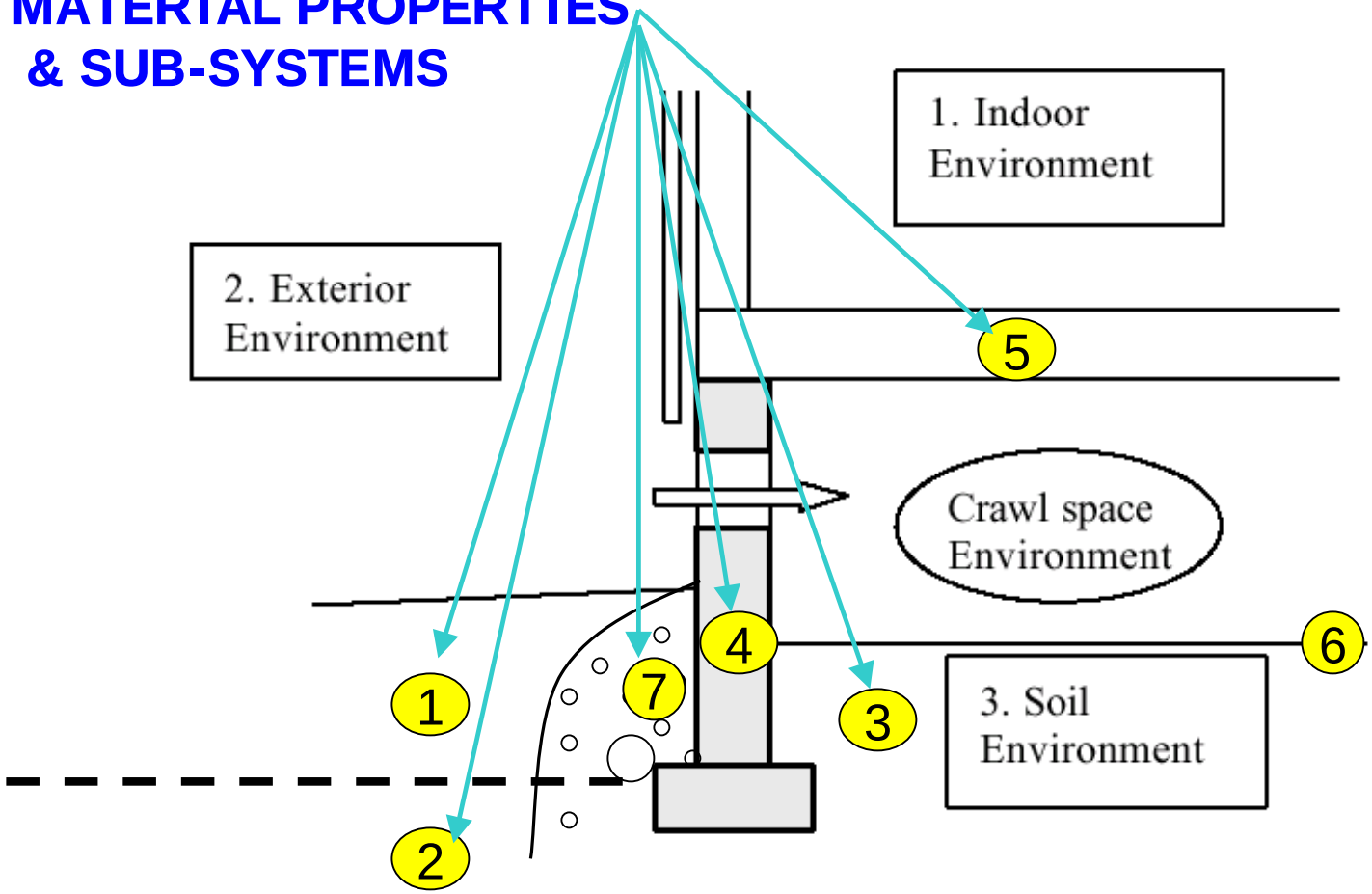
To Understand, need to recognize

FOUR ENVIRONMENTS



That's not ENOUGH ! !

MATERIAL PROPERTIES & SUB-SYSTEMS



Also Connectivity with 1st Floor and Roof

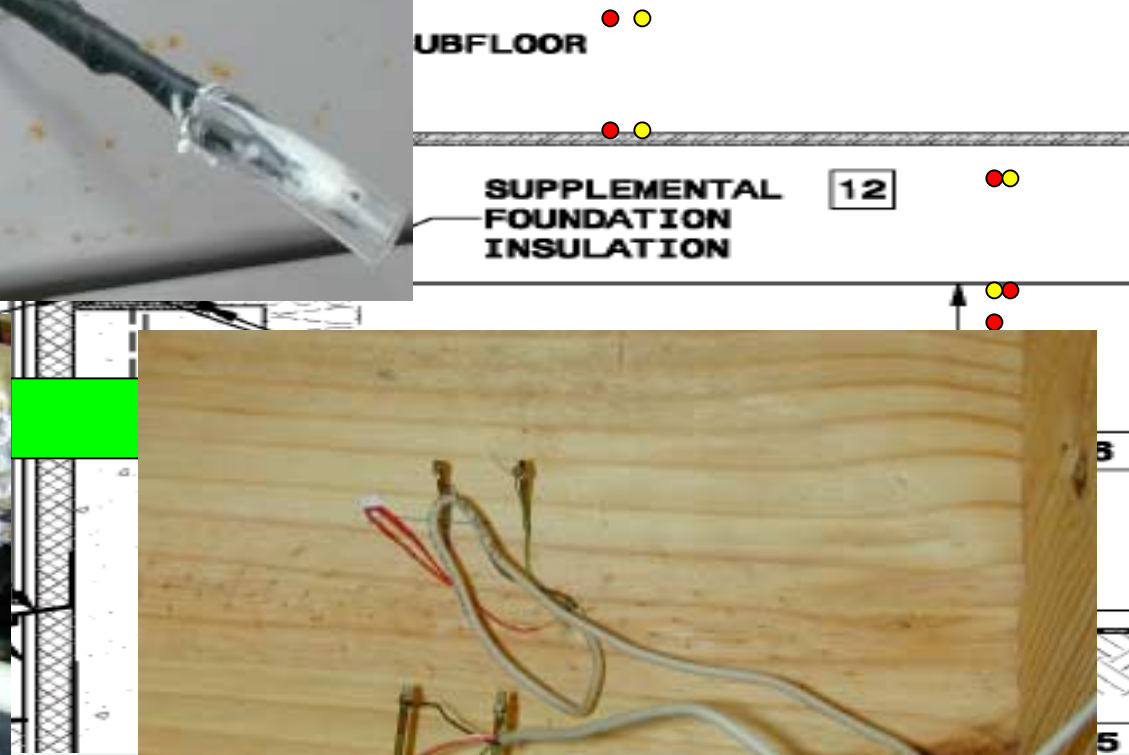
Pilot Study: Hygrothermal Analysis

Pilot Monitoring Study Includes:

- The crawlspace and home conditions have been monitored for between 2 study homes using hard-wired data logging systems and periodic monitoring visits. All homes are located in North Carolina.
- ORNL has collect data recorded on an hourly basis.
- Crawlspace data includes moisture levels; temperature and pressure conditions; exterior conditions such as solar irradiation, precipitation, temperature, relative humidity, wind speed and orientation. The field monitoring work provide measured hygrothermal performance data for crawlspaces that are ventilated or sealed.

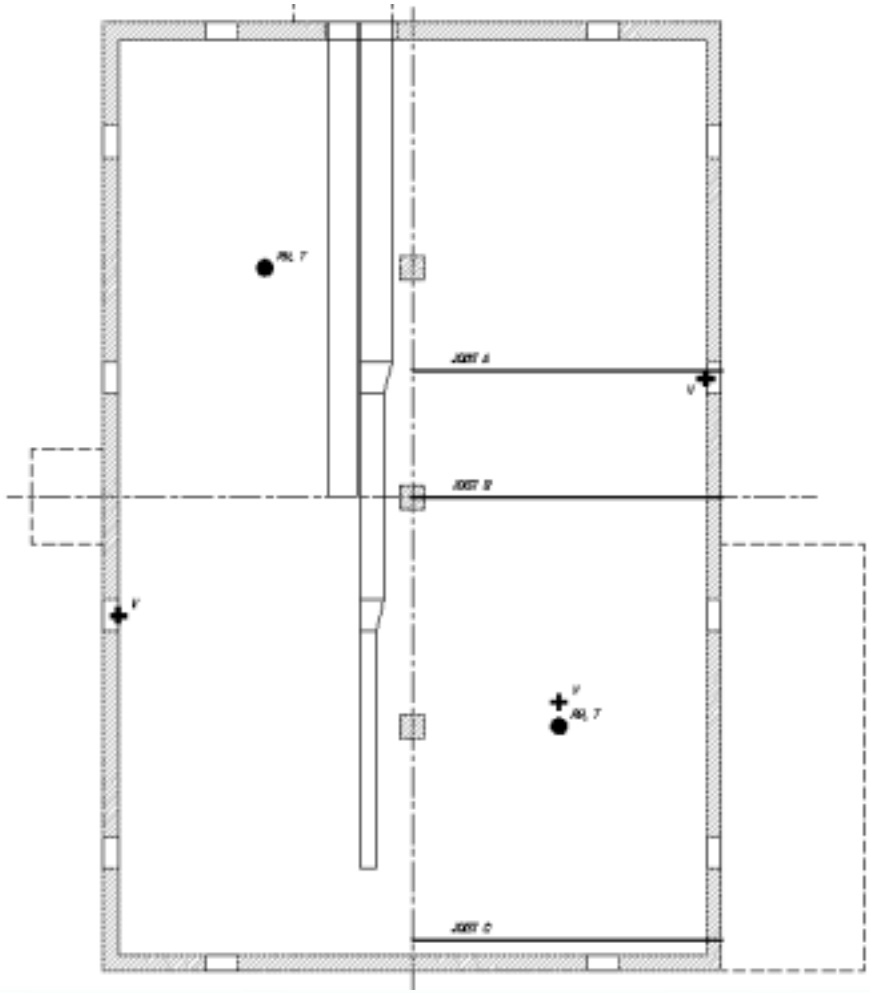
ISTRUMENTAT

No	Description
25	Moisture Pins
23	Thermistors
2	Bi-Directional Air Velocity
3	Soil Moisture Probes
2	RH and Temp sensors
4	Low-pressure averaging s
Sensor Subtotal	
1	Data Acq Main System



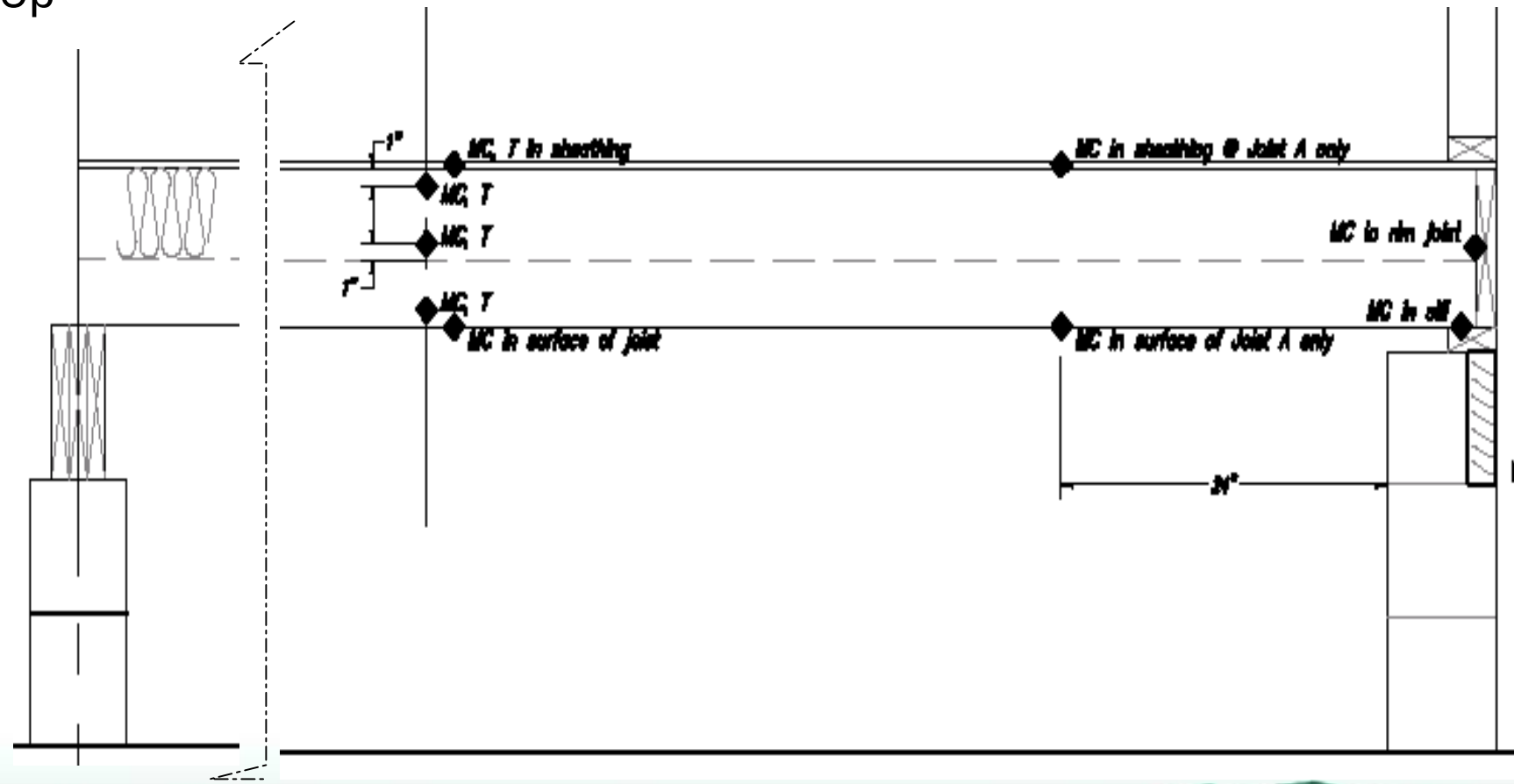
PILOT STUDY INSTRUMENTATION

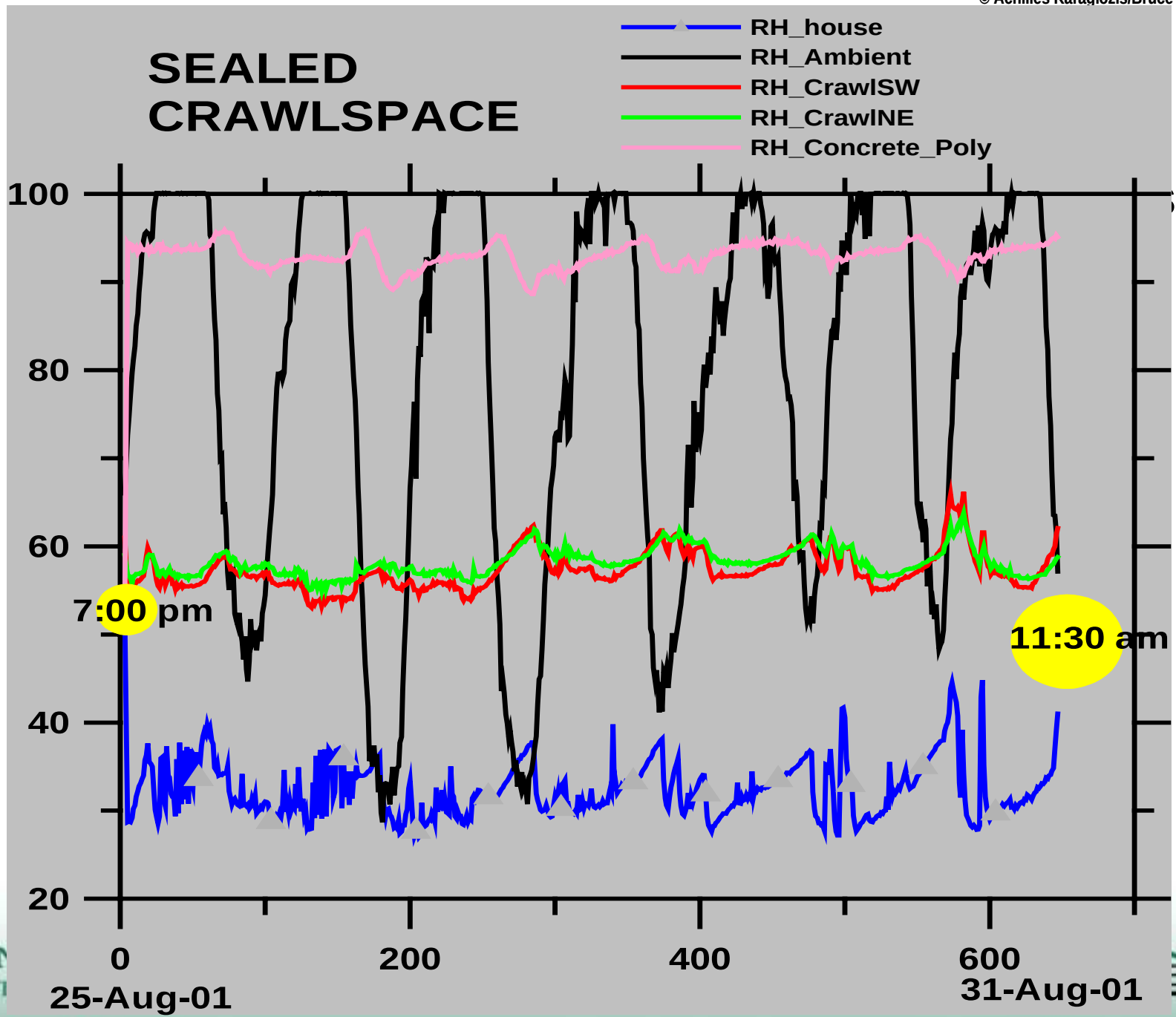
Set-Up



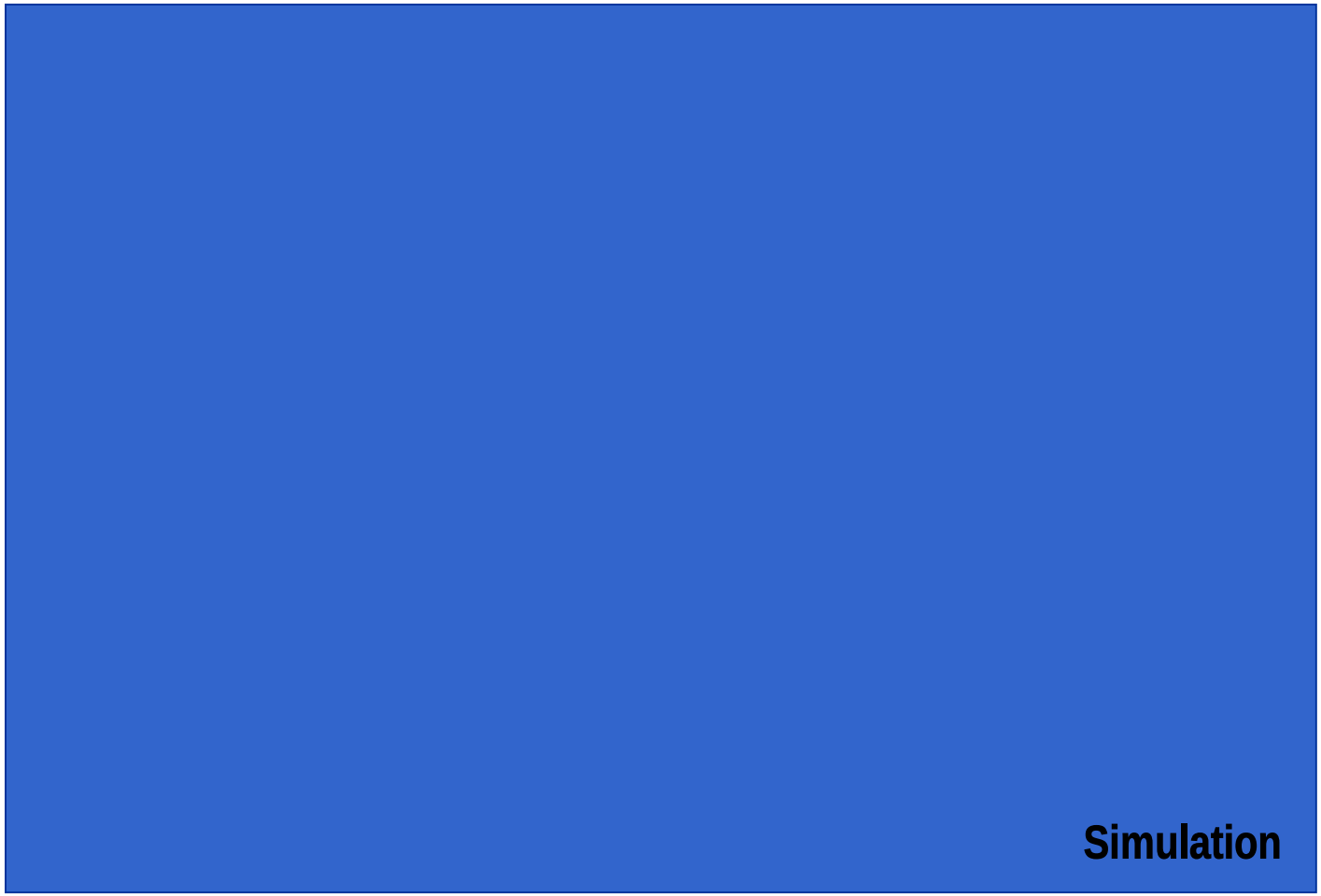
PILOT STUDY INSTRUMENTATION

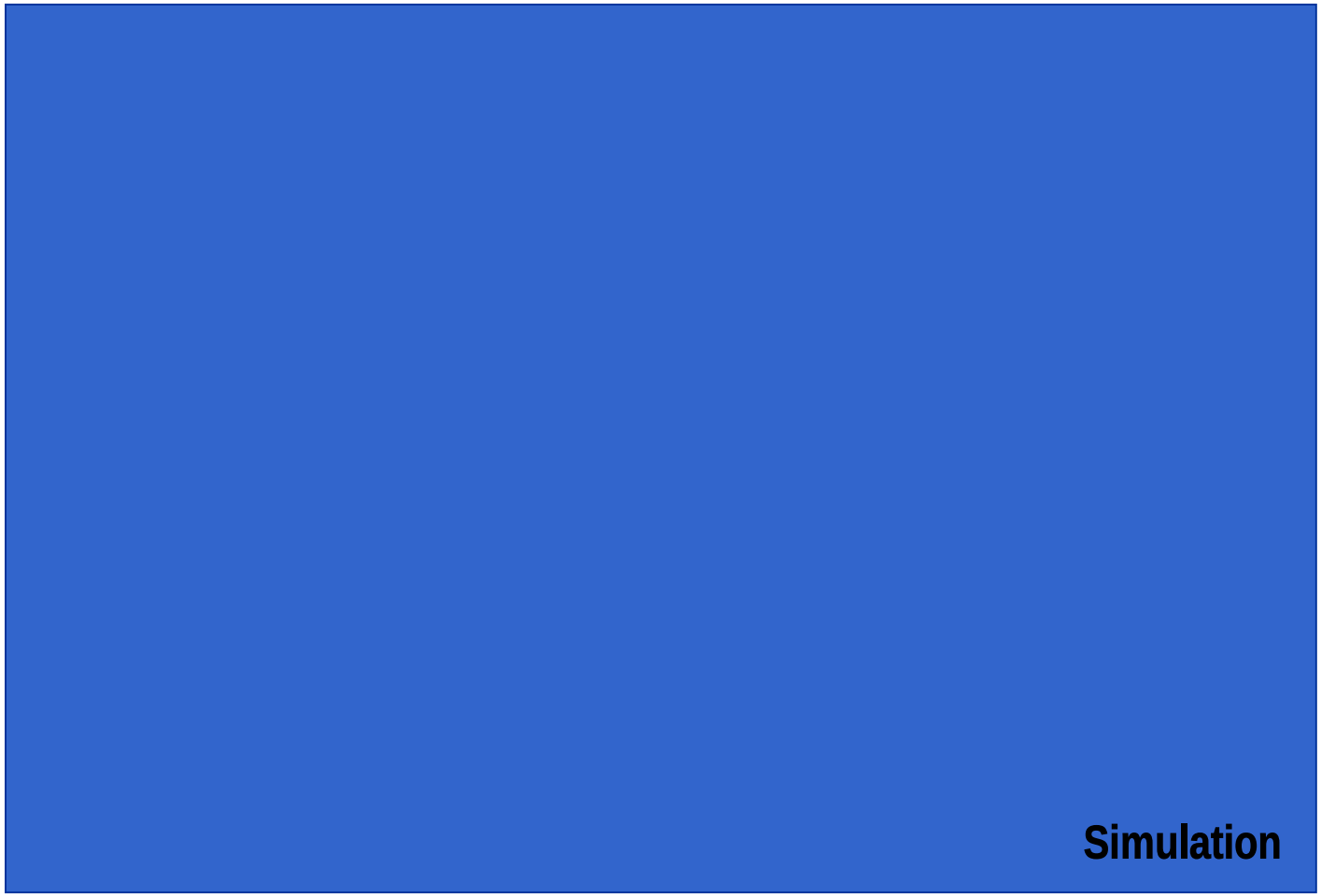
Set-Up

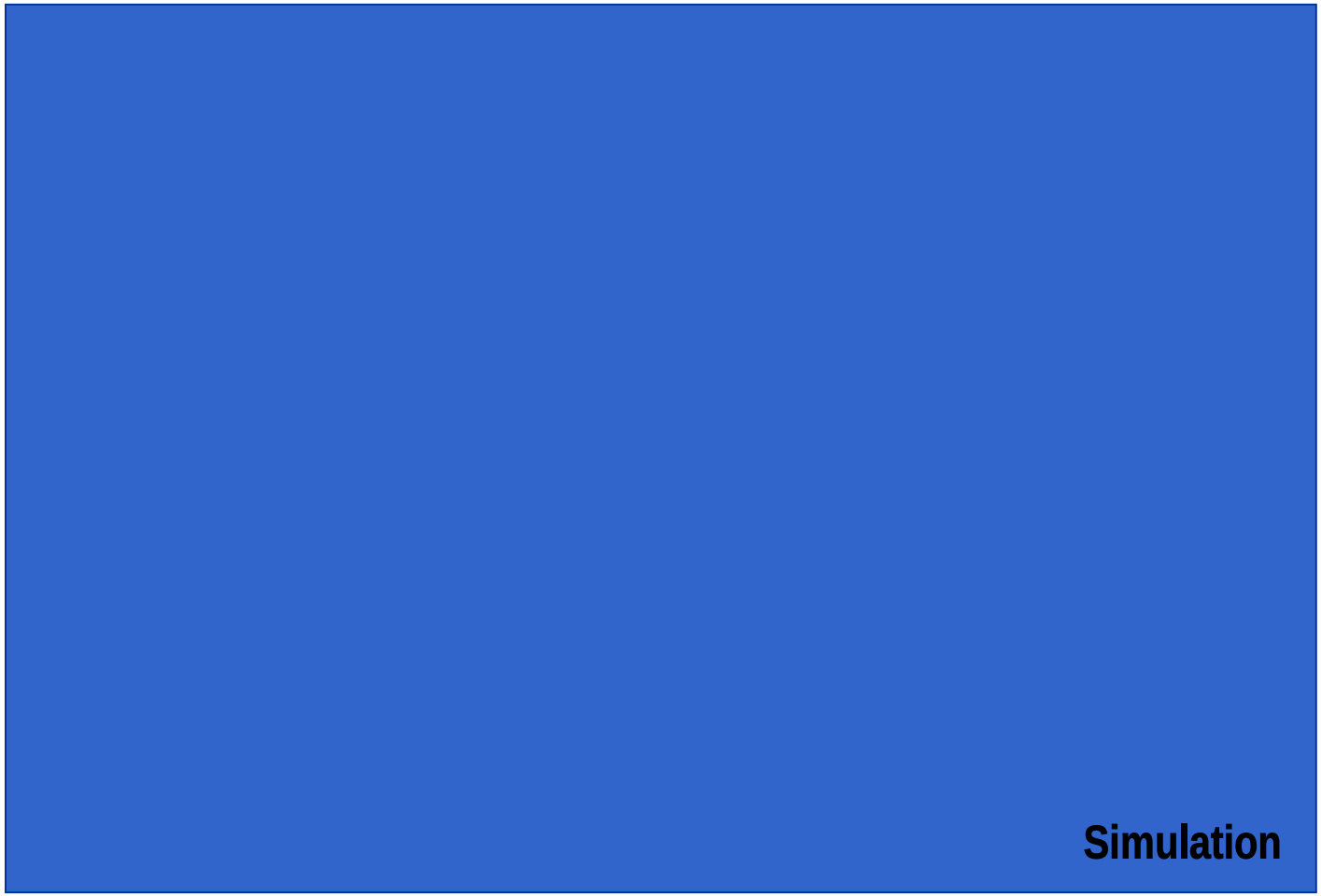


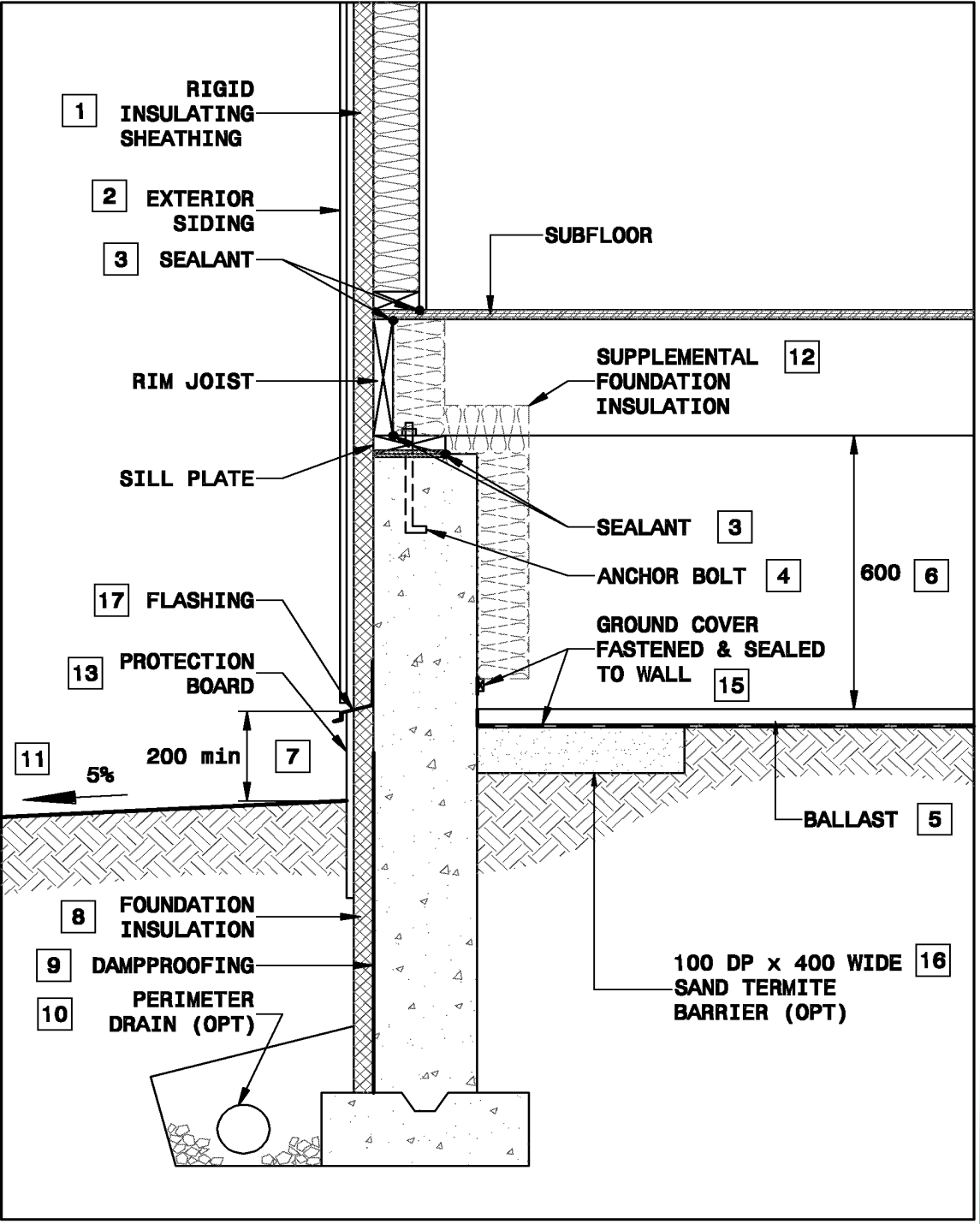


RESULTS









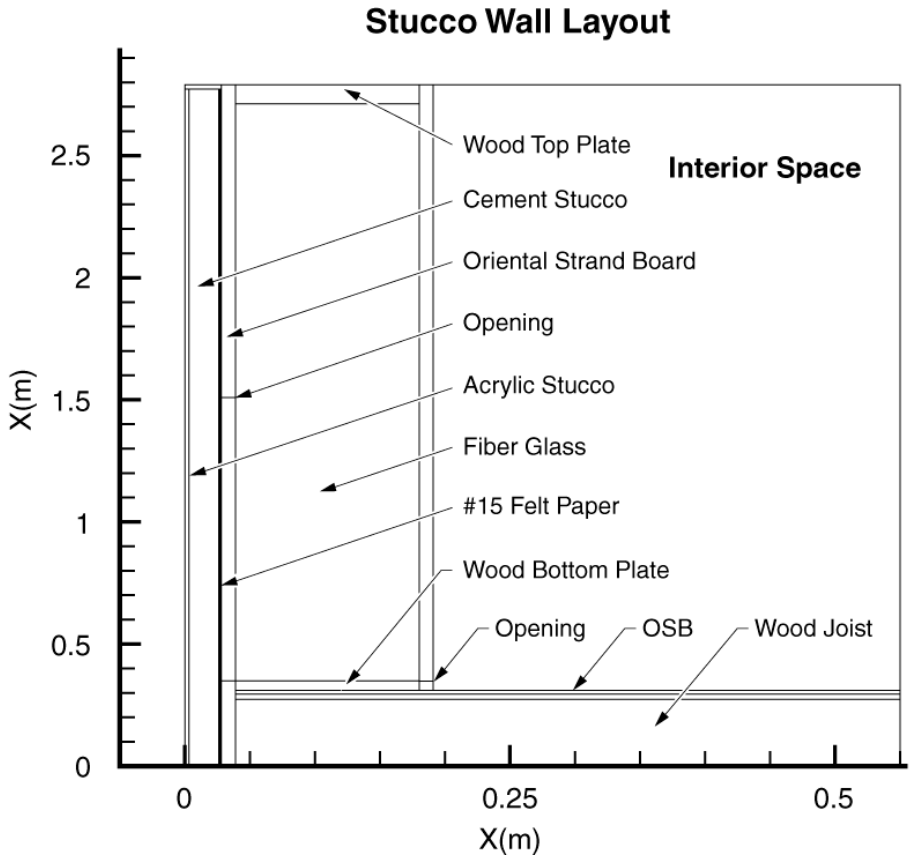
Good crawlspace Design

- continuous insulation
- air barrier
- drainage
- capillary wicking
- ensure some ventilation w/ interior

UT-BATTELLE

4. Seattle Performance

Wall Moisture Performance to Water Leakage

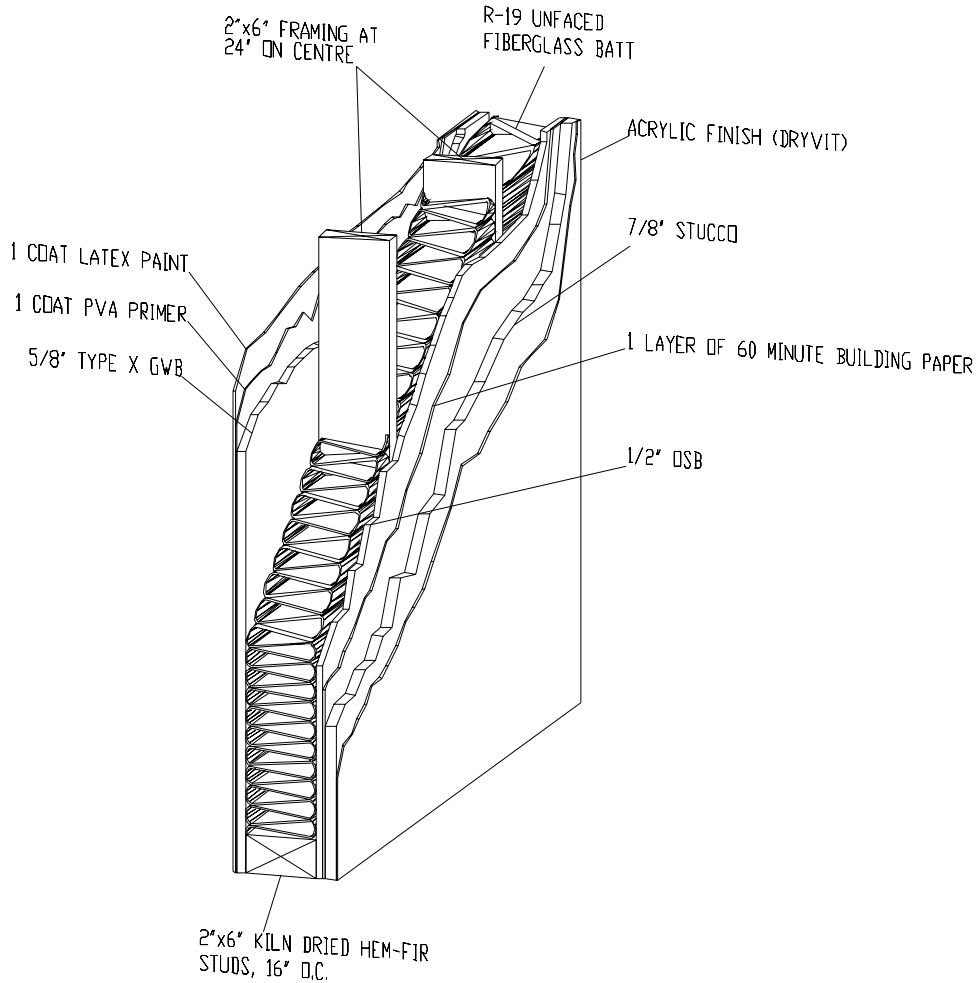


case 1: Effect of Water Penetration

case 2: Definition of Damage

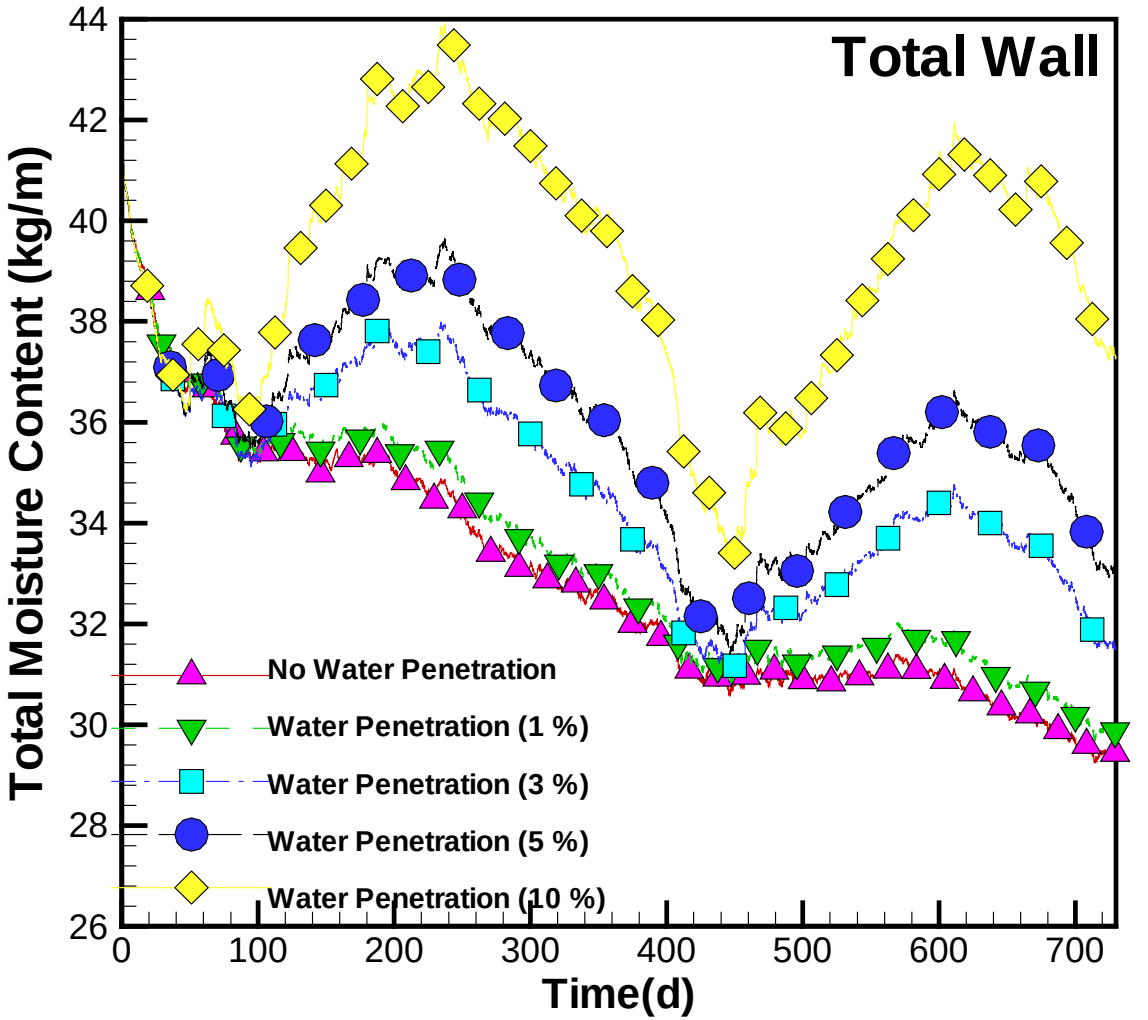
Ref.:Karagiozis

4. Seattle Performance



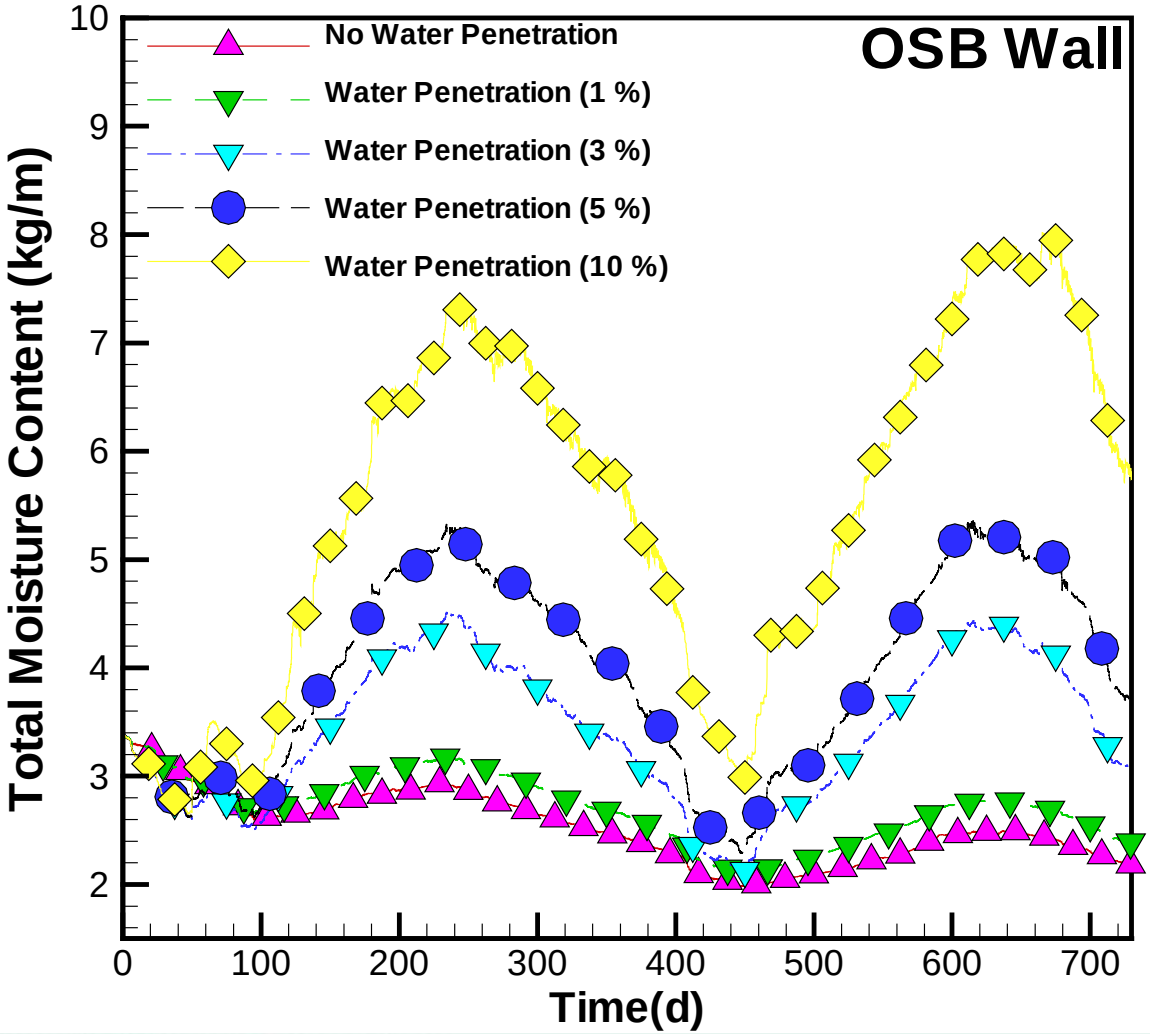
Ref.:Karagiozis

4. 2-Dimensional Example Case



Ref.: Andreas Holm

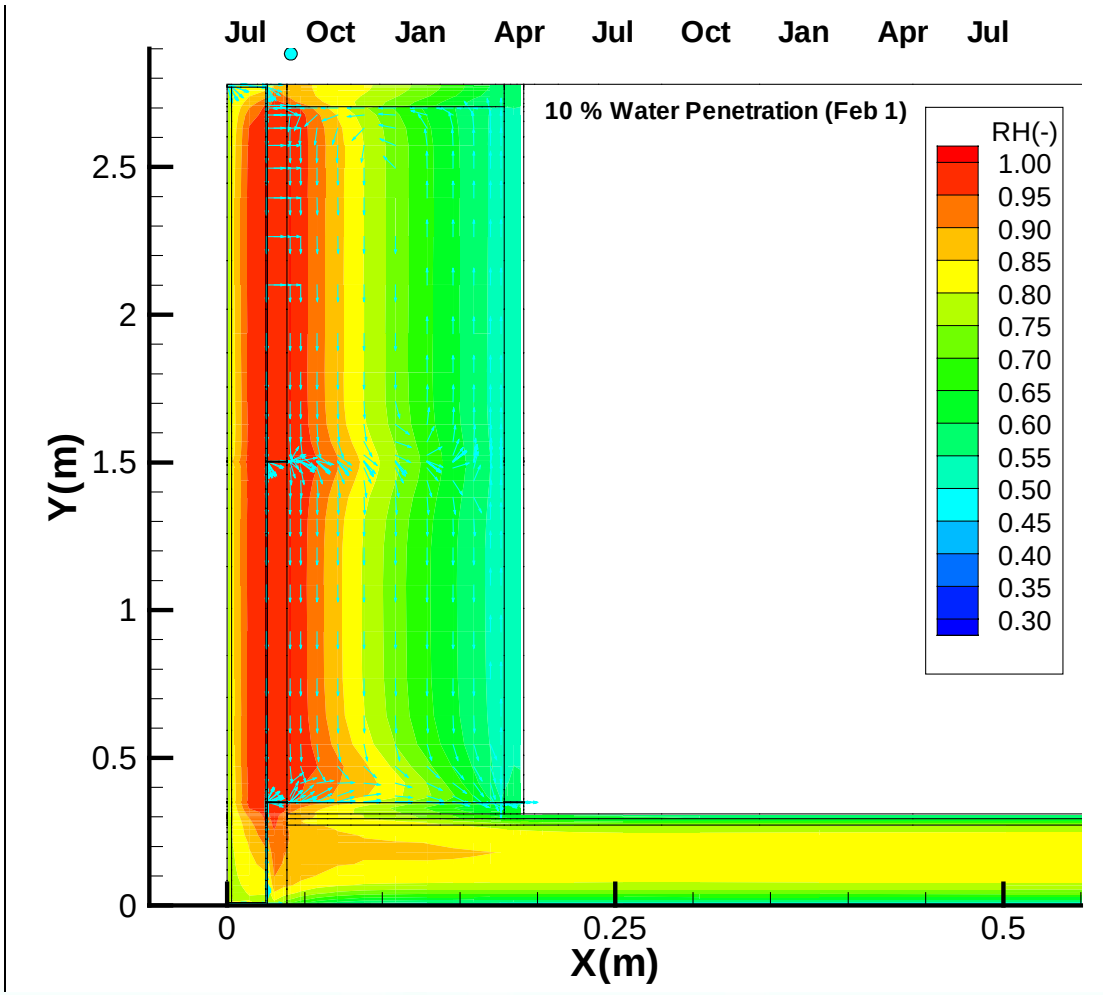
4. 2-Dimensional Example Case



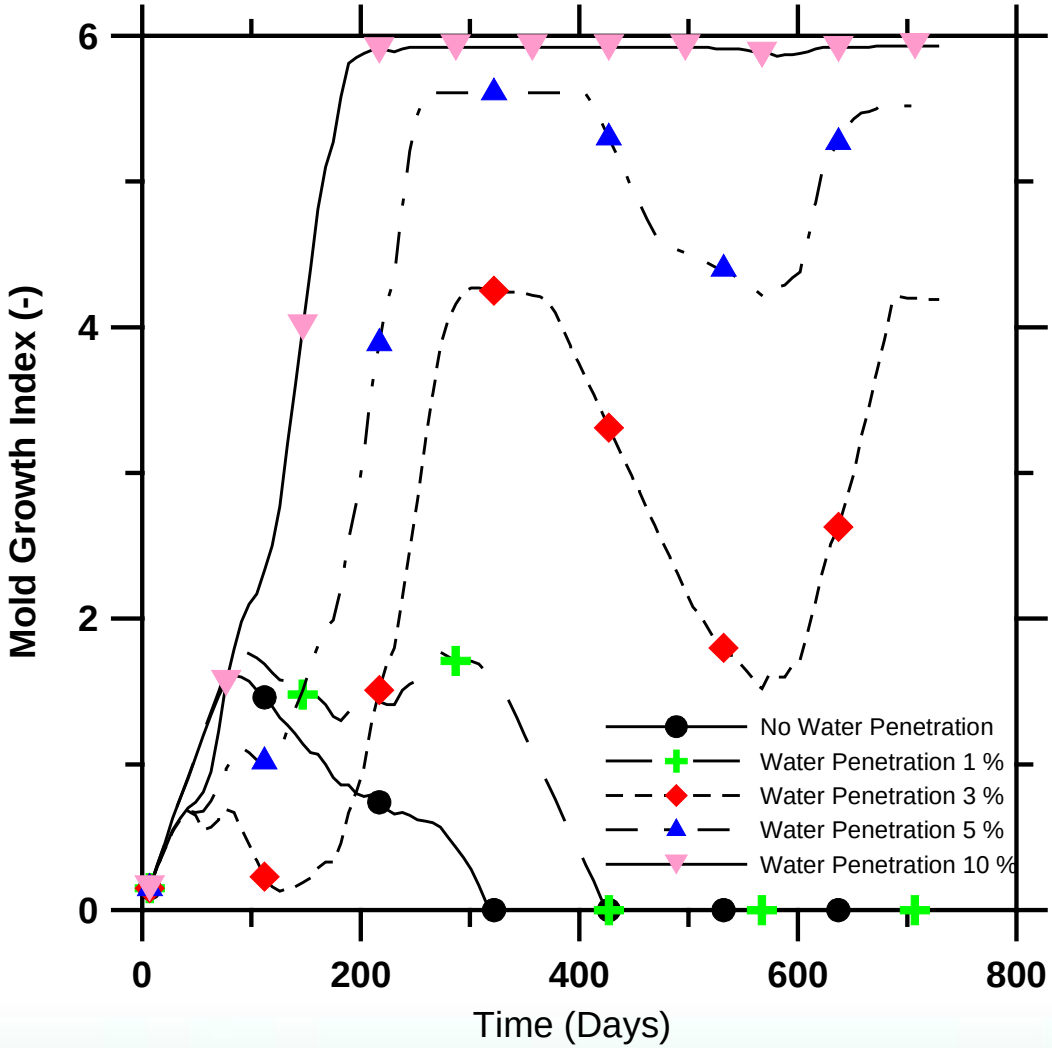
Look at Sensitive Element of Construction

Ref.: Andreas Holm

4. 2-Dimensional Example Case

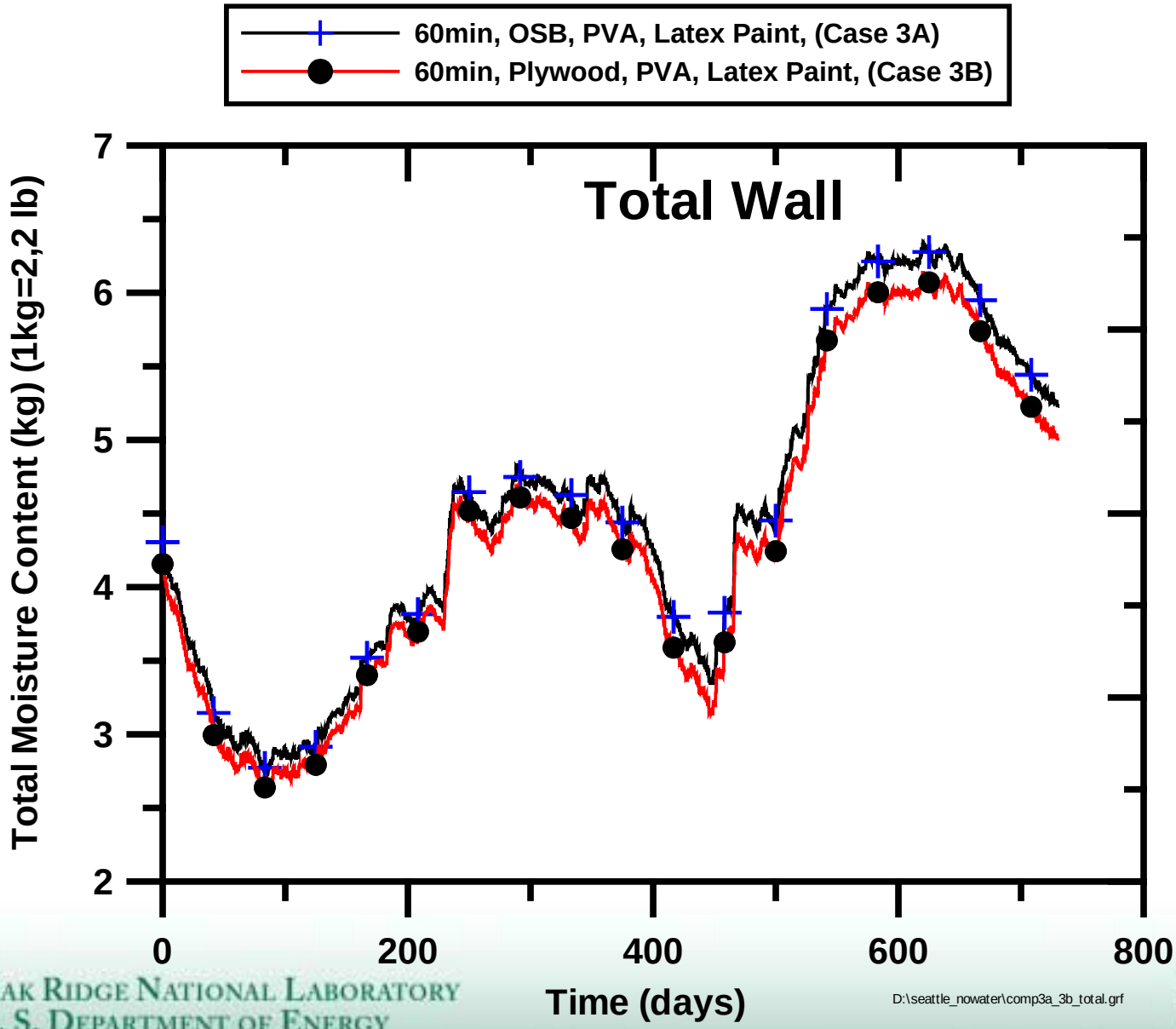


4. 2-Dimensional Example Case

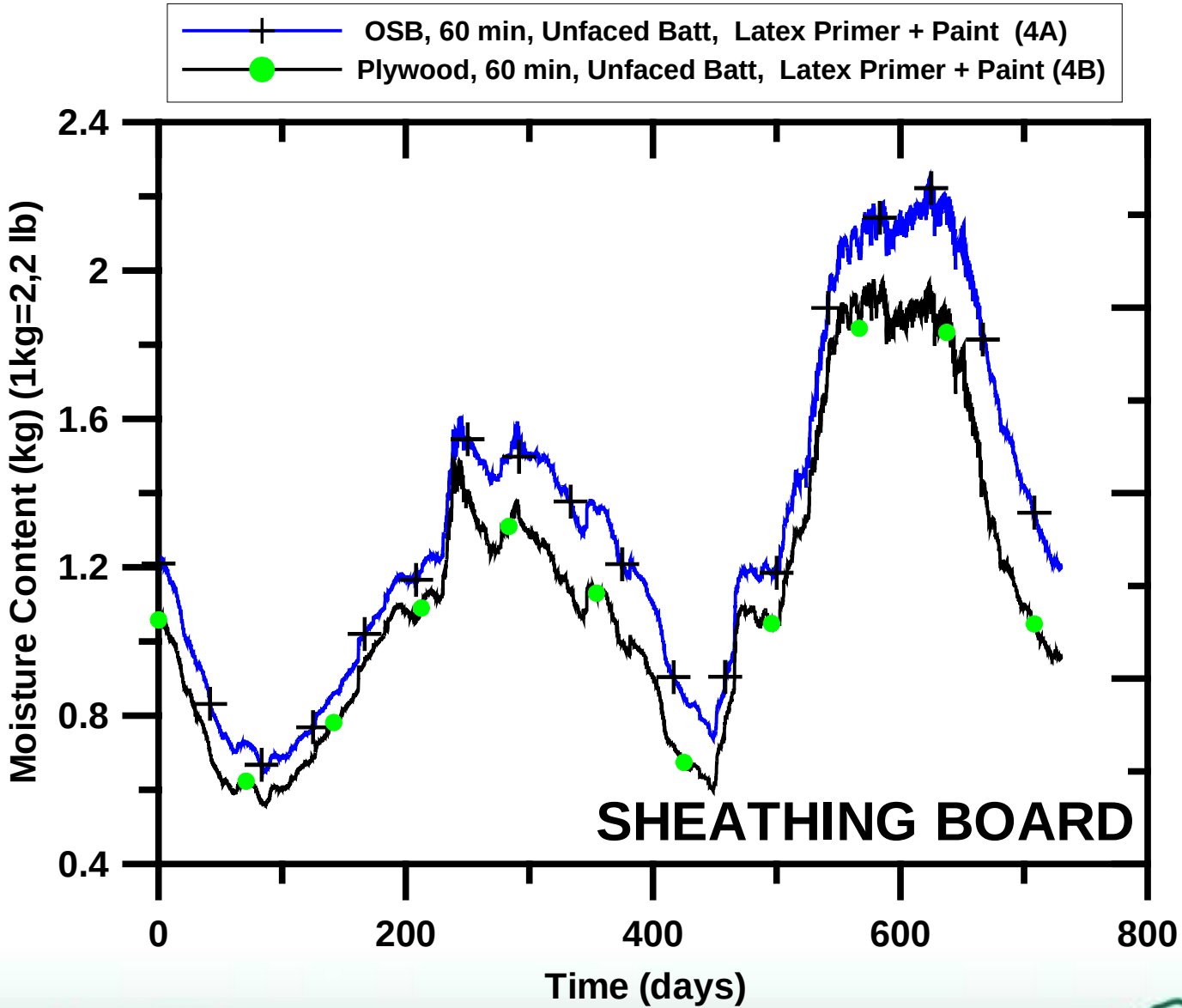


Ref.: Andreas Holm

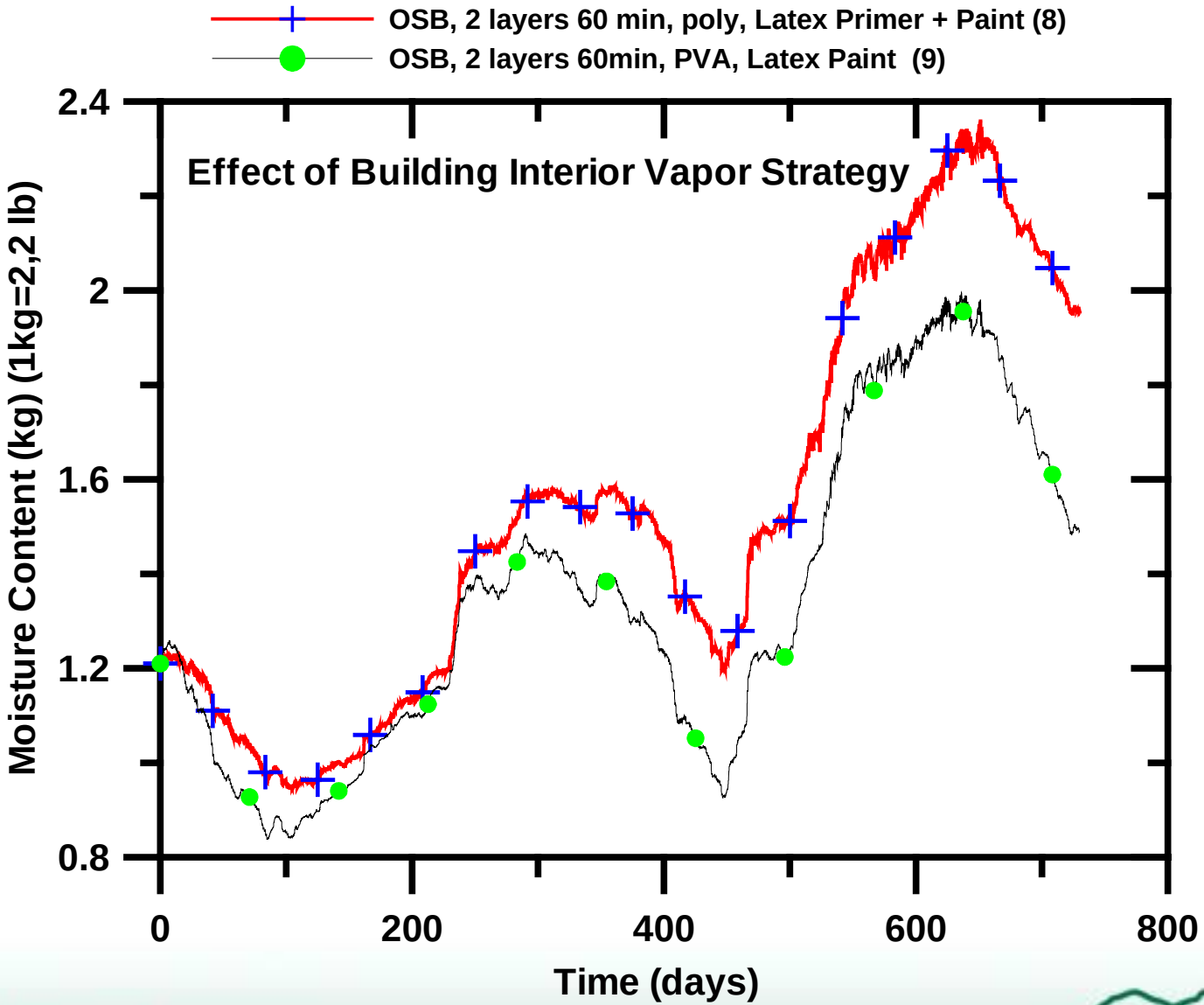
Seattle Results



Seattle Results

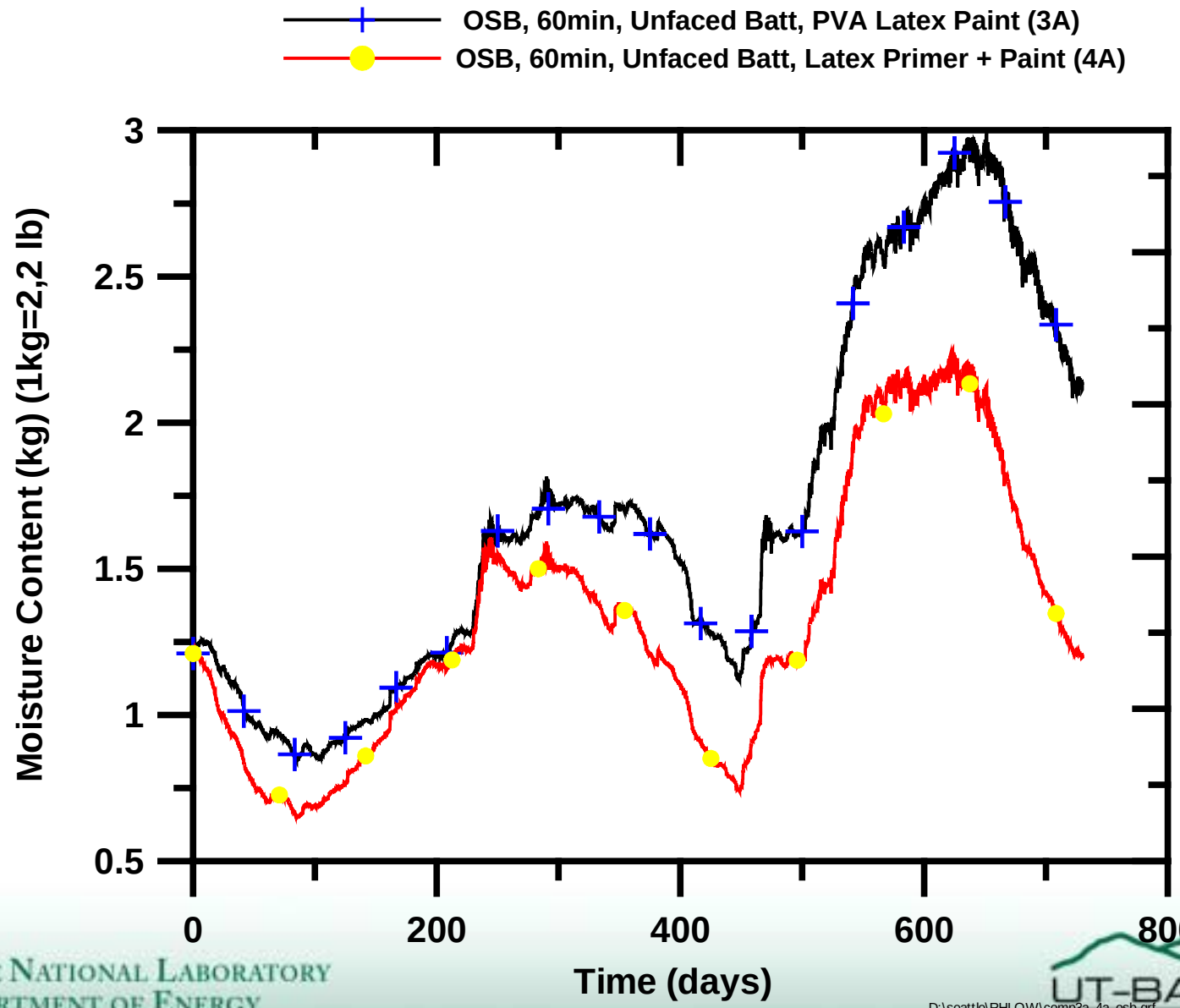


Seattle Results

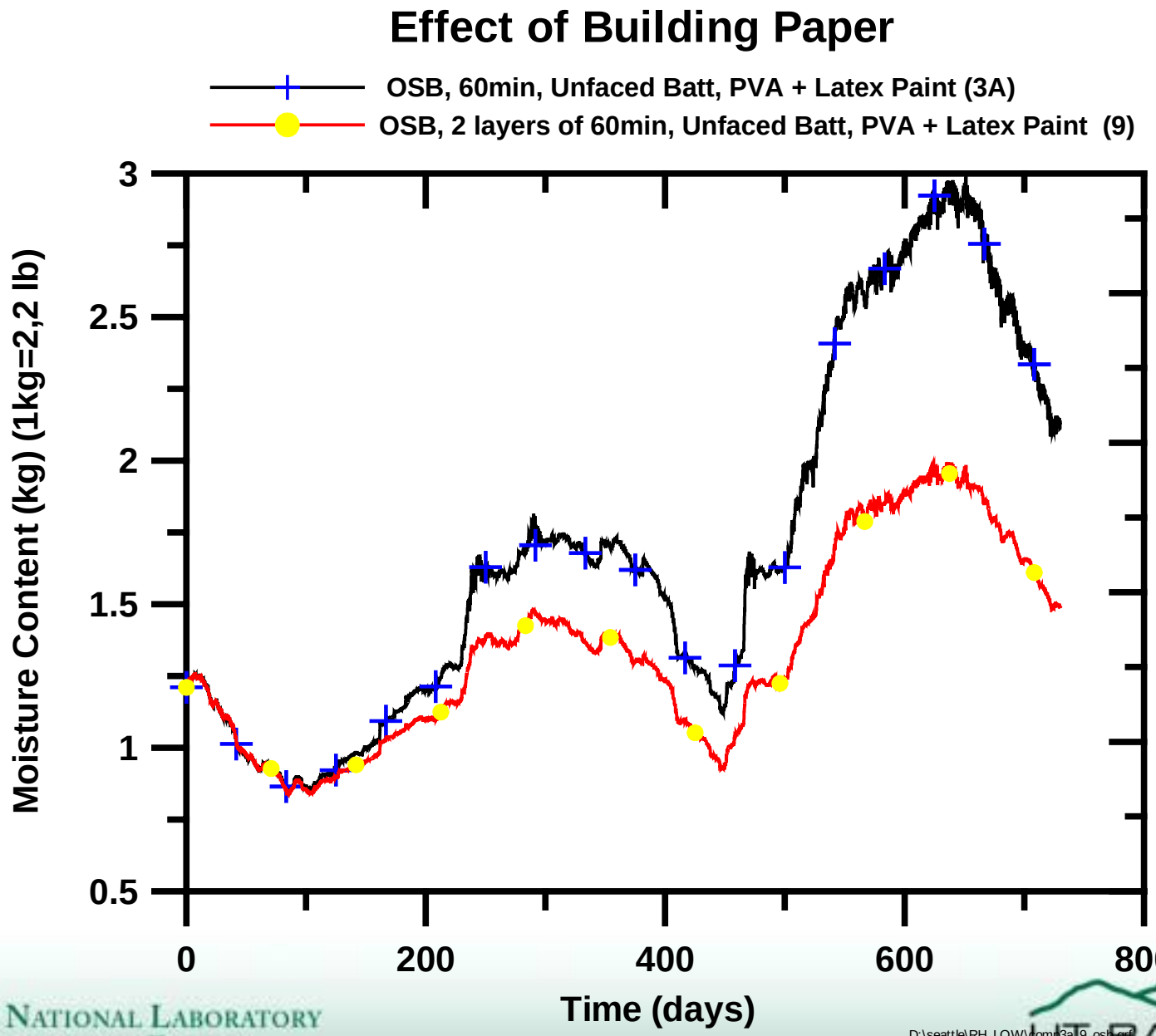


Seattle Results

Effect of Building Interior Vapor Strategy

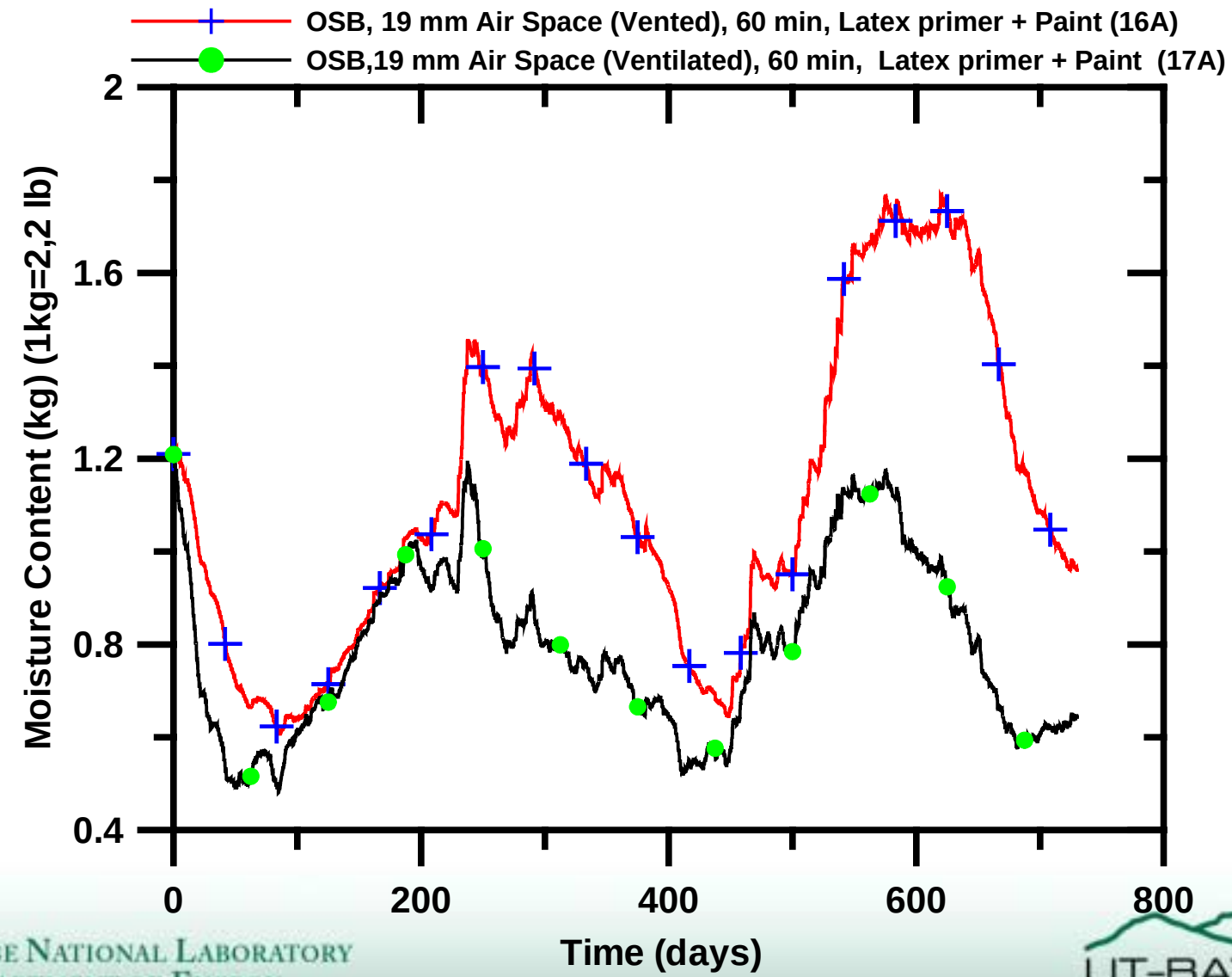


Seattle Results

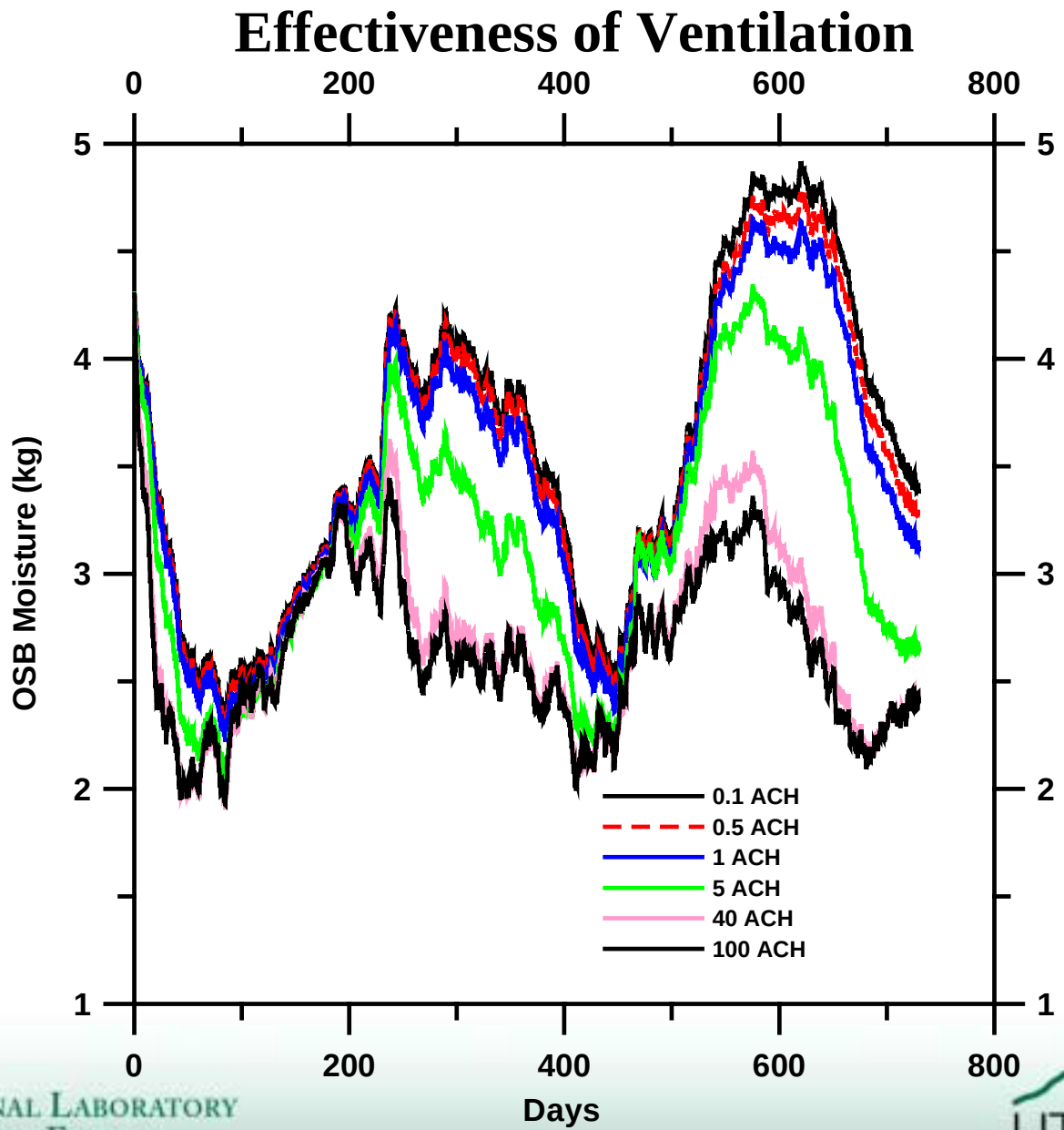


Seattle Results

Effect of Vented Air Space



Seattle Results



Seattle Results